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WORLD-WIDE COMMUNICATIONS USING SATELLITE REPEATERS

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1. Introduction

Dr. Robert H. Goddard, founder of American rocketry and a world famed pioneer in rocket discovery and invention once remarked to his critics: "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

This remark applies very appropriately to the subject of my talk this evening on "World-Wide Communications Using Satellite Repeaters." In 1955, five years ago, even before the first man-made satellite was launched into space, Dr. John R. Pierce, of Bell Telephone Laboratories, published a technical article[1] pointing out the possibility of using satellites as a means of transoceanic communications. The practiability of such communications was verified in the Echo I experiment which commenced on August 12, 1960 and which has been widely heralded in the press and technical literature of the past several months.

In addition to the importance of satellite communications to the military, such systems can provide the means of knitting the people of the world more closely together and thus serve as a deterrent to war and a boon to international commerce and industry. While satellite systems have already been proposed for communication to moving vehicles, this talk will be concerned primarily with overseas point-to-point communications.

2. Present Overseas Communication Facilities and Future Requirements

The question might well be asked why the development of satellite communication for overseas service is necessary in view of the extensive cable and radio facilities which already gird the world. The answer is that existing methods are inadequate to meet the expected increased demand for future world-wide communications while satellite communication systems hold the promise of meeting this demand both economically and reliably.

The facilities which are used for public telephone service to and from the United States excluding communications to Canada, and Mexico, are shown on Chart 1. These facilities provide a total of 491 telephone circuits with direct connection to 66 overseas countries or areas and switched connections to 94 others. 226 of these circuits are radio, 256 are cable and 9 are open wire land line. They were used to handle nearly 4 million overseas telephone calls in 1960 and the load is increasing at the rate of about 15 per cent a year. In 1957, the year after the first transatlantic cable was placed in service, telephone traffic to England increased 90 per cent, an indication of how traffic increases when improved facilities are provided. In 20 years overseas messages are estimated at about 100 million annually, and together with the expected increase in private line requirements for digital data, telephone and teletypewriter services including the needs of the military forces, a total of about 12,000 overseas telephone circuits will be required. If growth at the same rate continues beyond 1980, several billion telephone messages will be handled by the year 2000 A. D.

In addition, it is estimated that, by 1980, there will be a requirement for a minimum of two 2-way television channels for closed circuit and network television between any pair of ground terminals of a satellite communication system.

Except for the relatively short "beyond-the-horizon" microwave systems being used to serve Cuba and the Bahamas, the radio circuits which serve most of the routes shown on Chart 1 use high frequency transmission. Conventional microwave systems can not be used since they require line-of-sight transmission paths with repeaters located every 30 miles or so.

While high frequency radio circuits served admirably during the early stages of development of overseas telephony, they can not be expected to meet future needs for the following reasons:

a. The entire high frequency spectrum is only 27 mc wide and the number of available channels is strictly limited.

b. The large number of sations using these frequencies and the very great interference range of these stations has resulted in increased interference in recent years.

c. Magnetic disturbances, static and selective fading frequently cause lost circuit time and below normal transmission.

d. High frequency transmission will not support wide band.

The possibility of meeting the future demands for overseas service by means of submarine cables has not been overlooked. Telephone cables are already in service to Europe, Hawaii, Alaska, Puerto Rico and Cuba and still others are in the

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[1] J.R. Pierce, Orbital Radio Relays, Jet Propulsion, Vol. 25, pp. 153-157, April 1955.

construction or planning stage. However, a submarine cable of the latest type provides a bandwidth of only 0.40 mc in each direction of trans., while a typical common carrier microwave channel accomodates a base band of 4 megacycles and a fully equipped microwave system provides a useful bandwidth of some 40 mc. The bandwidth of submarine cables is sure to increase, but the practicable bandwidth of microwave systems seems inherently greater.

3. Technical Considerations for Satellite Communication Systems

With this background on the future need of satellite communication systems, let's take a look at some of the technical factors involved.

Satellite communications systems can use either passive or active satellite repeaters. Passive satellite repeaters merely reflect the signals received from the ground station transmitter without supplying any amplification. Active satellite repeaters are equipped to pick up the signals from an earth terminal, amplify them and retransmit them to the desired location.

Irrespective of the type of satellite used, the transmission paths will be long compared to the average hops of about 30 miles used in conventional microwave systems. Formulas for computing the path loss for systems using both active and passive satellites are shown on Chart 2. In the case of a passive satellite system the total loss from ground-to-satellite-to-ground is proportional to the fourth power of the distance. This equation takes account of the fact that the power intercepted by the satellite is reradiated isotropically from the satellite. For an active satellite the loss of each hop is shown separately (ground-to-satellite and satellite-to-ground) and each is proportional to the square of the distance. The satellite repeater gain which is not included in these formulas makes up for much of the loss. In either the active or passive satellite cases the losses are very large. The additional losses as compared to a conventional 30 mile microwave path can be made up by increased transmitter power, increased antenna directivity, reduced receiver noise, and the use of special modulation schemes to reduce the audible effect of noise.

Tubes for developing more than a few tens of kilowatts in the microwave range are almost impossible today and their cost increases rapidly with increased power. In the case of active satellites, transmitter power is severely limited by the weight of the equipment including it's power supply and the related costs of orbiting the satellite. Primary power by solar batteries requires several pounds per watt, and the equipment required to convert this prime power into radiated signal increases with increasing power requirements. What this all adds up to is that space communication systems must be designed for the greatest possible economy of signal power.

Antenna sizes are also limited by various technical factors affecting cost, including physical size and weight, the increased accuracy of construction needed to realize the potentially high directivity and the greater accuracy required of the mechanisms that keep them aimed at their intended targets. The use of directive antennas in active satellites requires stabilization and means of controlling the direction of radiation.

The increased power and antenna directivity that can be achieved within these practical limitations is not sufficient alone to insure a satisfactory satellite communication system. The additional transmission advantage required, can be obtained however, by the use of modulation and detection schemes which reduce the effects of noise at the receiving terminals.

As is well known, the use of frequency modulation (FM) makes it possible to obtain improved signal-to-noise ratios and the amount of improvement is proportional to the deviation ratio employed. When an ordinary FM receiver is used the bandwidth of the receiver must be increased as the frequency deviation is increased. But, increasing the receiver bandwidth admits more noise and if the bandwidth is made too wide the noise will cause the system to "break". Fortunately, J.G. Chaffee of Bell Telephone Laboratories in 1939 invented an FM receiver which uses negative feedback to control the frequency of the beating oscillator in accordance with the instantaneous frequency of the incoming signal. Chart 3 shows a block diagram of such a receiver. By this means the "breaking" point can be extended to low signal levels, while maintaining the signal-to-noise improvement resulting from the wide deviation of the transmitted signal. The overall improvement comes about because wide swing is used on the air, where reduction of noise is so important - but in the receiver, where bandwidth controls the breaking point, the swing is reduced by means of the negative feedback arrangement.

By the use of a maser amplifier, the intrinsic noise generated in the receiver itself can be held to negligible levels and the receiver can be made so quiet that the noise introduced by external sources must be considered. These external noise sources include galaxies, planets, the sun, the moon and other objects in space including the earth and the atmosphere surrounding the earth. In fact, any matter that has a temperature above absolute zero (-273° C or 0° K) produces thermal noise. The relationship of thermal noise power to temperature is expressed in terms of the well known equation

$$N = KTB$$

Where N is the thermal noise power in watts in bandwidth B,
K is Boltzman's constant,
T is the temperature in degrees Kelvin, and
B is the bandwidth in cycles per sec.

The noise figure of a receiver is the ratio of the noise generated in the receiver itself to the thermal noise of an ideal receiver. In recent years it has become common practice to talk about the noise properties of receivers in terms of their effective noise temperatures, rather than their noise figures. The relationship of effective noise temperature and noise figures is shown on Chart 4. By the use of a maser amplifier the noise temperature of the receiver can be reduced to about 7° K compared to 3000°K for a conventional microwave receiver. The source of noise is so low as compared to other sources that it is not controlling.

Now the important item is the external noise temperature normally seen by a ground terminal satellite receiving antenna. The radio signals transmitted to and from the satellite must pass through the earth's atmosphere. The thickness of the layer encountered depends upon the angle of the radio beam with respect to the earth's surface and is a minimum for signals transmitted directly upward toward the zenith. However, in order to effectively use a satellite moving relative to the earth as a relay point for long range transmission, it is necessary to direct the radio beam at it throughout a wide range of elevations. The heavy curved lines on Chart 5 show the temperature effect of oxygen and water vapor absorption on transmissions at different frequencies for various angles of elevation of the main beam of the antenna. The earth itself has a noise temperature of about 300 degrees Kelvin and it is necessary to use receiving antennas which have a minimum of back and side lobe radiation in order to limit system noise principally to that of the atmosphere (Chart 5). The horn-reflector antenna is being used for this purpose.

It appears from the heavy curves of Chart 5 that when operating at frequencies below about 10,000 mc, with antenna elevations as low as 5 to 10 degrees, the atmospheric noise will be less than about 30°K.

The sloping lines at the left in Chart 5 show the effective noise temp due to cosmic noise and how it varies with frequency. The lines marked "Cosmic Noise" and the oxygen absorption curves define frequency boundaries between about 1000 and 10,000 mc which would be most useful for satellite communications. Frequencies from 10,000 to 16,000 mc are less favorable but might be used. Frequencies about 20,000 mc do not appear suitable for reliable satellite communications due to increased absorption and rain attenuation.

This matter of system noise is very important since it becomes the basis for overall system design. The desired signal levels at the receiver input must be strong enough to override the noise by a good margin at all times to provide satisfactory service. The engineer then has a choise of various system parameters to provide the proper signal level. These include determination of whether active or passive satellite repeaters of the low level orbiting type or the 22,000 mile stationary type will be used, and the antenna gains and the transmitted power levels for the ground terminals and the satellites, and the modulation ratio. The maser amplifier, the FM receiver with feedback, and the large horn-reflector antenna constitute the most significant extensions of older microwave techniques to achieve practical satellite communications.

4. Project Echo

Project Echo is a passive satellite communication experiment undertaken by the National Aeronautics and Space Administration with the cooperation of the Bell Telephone Laboratories, the Jet Propulsion Labs, the Navy and others to confirm some of theoretical considerations as to the practicability of using satellites for long distance communications.

A 100 foot diameter sphere was placed in orbit approximately 1000 miles high with the orbital plane inclined about 47 degrees from the equator. The sphere was made of Mylar polyester film, 1/2 mil thick, about half the thickness of the cellophane on a cigarette package. The satellite's shell was covered with vapor deposited aluminum to provide radio wave reflectivity of 98% for frequencies up to 20,000 mc. Chart 6 shows the Echo balloon. The satellite travels at about 16,000 miles per hour, circling the earth about once very two hours (118 minutes). Two waferlike tracking beacons, with small whip antennas are attached to opposite sides of the sphere at its equator, each transmitting on the same frequency 107.94 mc.

The primary communication sites for the initial experiment were the Bell Laboratories installation at Holmdel, N.J. and the NASA/Jet Propulsion Laboratory station at Goldstone, California. The terminal at Holmdel is equipped with a 10 kw FM transmitter operating at 960 mc, a 60 foot diameter parabolic transmitting antenna, a 20 x 20 foot aperture horn-reflector receiving antenna, a three level maser amplifier using liquid helium to hold the maser near absolute zero temperature, receiver with negative FM feedback, a radar receiving antenna for radar tracking, and a digital analog converter and other equipment for keeping the antennas pointed at the satellite. Chart 7 shows a general view of the Holmdel site.

The Goldstone terminal was similarly equipped, but used a frequency of 2390 mc for transmission, a parametric receiving amplifier (300° K) and 85 foot diameter parabolic antennas for transmitting and receiving.

Chart 8 illustrates the overall system, showing how the frequencies are used for two-way communication by reflection from the satellite. Chart 9 shows the area in which the satellite must be located to be visible simultaneously from both

Holmdel and Goldstone Lake. The chart shows typical passes of the satellite through the mutually visible area. Six such passes occur per day with an average time of 12 minutes per pass, the maximum being about 16 minutes. The ragged outline of one side of the mutually visible area is caused by mountain range obstructions seen from Goldstone.

Precise data on the satellite location is required for use in properly orienting the ground station antennas which must be contolled to within about 0.2 degree. At Holmdel several methods are used. The primary one is the predicted orbit method using data provided by NASA's Goddard Space Flight Center. This center collects tracking information from Cape Canaveral, Trinidad, Rome, N. Y., Goldstone, Calif., Millstone radar station at Westford, Mass., NASA's Minitrack network and optical tracking stations operated by the Smithsonian Astrophysical Observatory, Cambridge, Mass. This information is fed into a 704 computer to obtain current and predicted orbital information. Predicted orbital data for two second intervals in terms of azimuth, elevation and time is transmitted by teletype to Holmdel and other participating stations in the form of digital data. At Holmdel this data is converted to the analog form used to control the machinery for orienting the antennas.

A system for radar tracking of the satellite is also provided in connection with the Holmdel installation. This system utilizes pulsed radar signals at a carrier frequency of 961 mc transmitted over the same 10 kw transmitter as that used for communication (960.05 mc) and using about 10% of its power. The radar receiver is located about 3 miles away. In addition, Holmdel has available an M33 radar optical tracking system for back up use on clear days.

The signal levels received at Holmdel from Goldstone were found to agree within a db or so of the predicted values and provided a single telephone circuit of excellent quality. I will now play for you a tape recording of the original message transmitted over the Goldstone-Holmdel system during the first pass of the satellite on August 12.

To demonstrate the possibility of using this type of transmission for public telephone service, a call from California was patched at Holmdel through the telephone exchange at Middletown, New Jersey.

Tests with the Naval Research Laboratory at Stump Neck, Maryland included facsimile picture transmission. Signals transmitted from Holmdel have also been received via the satellite at the Jodrell Bank experimental station in England and at a radio site located near Paris. In still another test, a signal transmitted from Goldstone via the satellite was received at Holmdel and re-transmitted to Stump Neck, Maryland by a second reflection from the satellite.

The tests showed that the use of predicted orbital data to control antenna pointing is feasible. The radar tracking arrangement also worked satisfactorily. Optical tracking, when conditions permit, appears to be the most reliable and accurate of the three methods used. The test data obtained during the Echo experiment has met expectations and fully confirms the technical possibility of using satellites for transoceanic communication.

5. Satellite Arrangements

In order to meet the need for economical overseas services by satellites, wide band transmission will be required as contrasted --- To attain a 5 megacycle bandwidth suitable for 600 telephone circuits or one television channel using a passive satellite in an orbit 2500 miles high for service between Holmdel and London or Paris, antennas over a hundred feet in diameter and several tens of kilowatts of transmitter power would be required. This brings up a number of serious problems.

Plans are accordingly underway to the use of active repeaters having a power of 1 or 2 watts radiated from satellites in more or less random orbits several thousand miles above the earth. Such a repeater might use a slot antenna producing a radiation pattern similar to a dipole and the satellite could be spun to keep the axis pointing in a known direction. Chart 10 illustrates such a satellite. If a 60 x 60 foot aperture horn-reflector antenna and a maser amplifier with an FM feedback receiver are used at the ground receiving terminal, such an arrangement will provide a suitable signal-to-noise ratio for a 5 mc baseband with an FM deviation of $\pm$ 50 mc. Since it would not be practicable to use a maser receiver with FM feedback in the satellite, transmission from ground-to-satellite will require a transmitter power of 1,000 watts with a 60 foot diameter parabolic antenna. To avoid interference at the satellite, different frequencies for transmission and reception will be needed. Chart 11 shows the frequencies required for an active satellite arrangement. In the scheme considered here each of these frequencies, with suitable guard bands, occupies a bandwidth of about 125mc or a total of some 500 mc for one two-way broadband system. Ultimately for reasons of economy and capacity it would be desirable to put repeaters for several channels aboard each satellite.

With a low powered repeater of this kind, it is possible to operate many satellites in different parts of the sky simultaneously on the same radio frequencies, interference being avoided by means of the directivity of the ground station transmitting and receiving antennas.

The immediate technical problem in such a system is satellite life. It is believed that a 1-watt traveling wave tube can be made with a life of 10 years or more and it seems possbile to construct the remaining parts of the repeater out of long-life solid-state components. To

survive the radiation of space, solar cells must be protected by transparent covers of quartz or other material. These and other technical problems are being investigated by the Bell Laboratories. The hope is to achieve a 10 year life for the satellites.

Use of low level satellites such as that just described means that a multiplicity of satellite repeaters is needed to assure uninterrupted service. It has been estimated that about 30 such satellites in somewhat random polar orbits 2500 - 3000 miles high would provide a commercial grade service between New York and London or Paris and that some 50 such satellites will be required to provide service from the U.S. to all areas of the world.

The use of an active satellite in a 24 hour orbit 22,000 miles above the earth would be visible over one-thind its surface and might be used to provide service between points in this area using only a single satellite. However, the means required to place such a satellite in orbit and keep it there, as well as the problem of equipping it with directive antennas arranged for alignment toward the earth are complex, requiring orientation equipment involving electronics, flywheels, gas jets, and the like. Furthermore, the path length would be sufficiently long that transmission time would create a problem for two-way voice communication, due to the requirement for echo suppressors and the appreciable time lag of one-half second or more between the end of a transmission and receipt of the reply.

Although the stationary repeater holds considerable promise for the future, it seems much farther away for commercial two-way voice communications than the low orbit active repeater.

6. World-Wide Service Using Satellites

A preliminary plan to illustrate how satellite communications might be used to provide service from the U.S. to other areas of the world has been prepared. This plan involves some 26 ground terminals and active satellite repeaters in somewhat random polar orbits 3,000 miles high.

Since a given satellite at this height would only remain in the area of mutual visibility between any pair of terminals for periods up to 30 minutes or so, enough satellites must be provided so that at least one will be visible a very large percentage of the time. Rough estimates indicate that about 50 satellites will suffice for the 26 terminals in the plan studied. Chart 12 shows the ground station locations and connections assumed. The same frequencies can be shared between each of the connections illustrated on this chart provided they always operate from different satellites. To avoid interference use of the satellites must be carefully coordinated to insure that two or more ground stations never illuminate the same satellite on the same frequencies.

In order to avoid interruptions to service in switching from one satellite to another as the satellites pass through the mutually visible area, duplicate transmitting and receiving antennas and radio equipment will be required at each terminal. The terminals also will require standby radio equipment, regular and emergency power supplies, land, buildings and access roads. The estimated cost of a typical ground station, exclusive of carrier terminal equipment, providing one broadband channel in each direction of transmission is $2,500,000.

The present cost of launching even comparatively light satellites appears to be several million dollars. However, large vehicles of the future might launch large satellites, or might launch many smaller satellites at one time for a cost comparable to present-day launchings. Based on a forward look the cost per satellite equipped for one two-way broadband channel has been estimated at $1,000,000.

The estimated cost of the 26 ground installations indicated on Chart 12 plus the 50 satellite repeaters comes to a total of $115 million. If an additional two-way broad band channel is provided, the satellite costs would about double, due to weight considerations, and the additional ground station equipment would cost about $200,000 per station. This would bring the estimated cost of the total world-wide system to approximately $170 million. The estimated cost of a satellite system between only two points such as New York and London or Paris and providing a single two-way broad band channel suitable for 600 telephone circuits is about the same as the cost of the original transatlantic cable, but it's traffic capacity is more than 10 times that of the cable. While substantial reductions are being made in cable costs, the per circuit costs of satellite systems looks very attractive where large traffic loads are expected.

7. Frequency Requirements

As mentioned earlier, a satellite communication system designed along the lines indicated, to provide one two-way broadband channel may occupy a total radio frequency bandwidth of 500 megacycles or so, depending upon the system parameters finally decided upon. In order to meet the 1980 circuit requirements it will be desirable to pack four such broadband channels into each active satellite, making for a frequency requirement of 2000 megacycles, preferably in the range 1000 to 10,000 Mc and not higher than 16,000 mc.

The sharing of frequencies by satellite communication systems and ground microwave systems is fraught with problems. Satellite system ground transmitters will have powers up to thousands of times those used in conventional microwave systems and so are potent sources of interference. Conversely the ultra-sensitive receivers of satellite systems are highly vulnerable to otherwise inconsequential radiations from ground microwave systems.

Fitting satellite communications systems into the frequency spectrum is a problem requiring the utmost of careful, long-term planning. Already the Federal Communications Commission has put all microwave users on notice that changes in current usage may be required to meet possible requirements for space communication needs.

Furthermore, the problem is not limited to this country. International cooperation and coordination is essential. The subject of frequencies for space communications is on the agenda for the next meeting of the C. C. I. R. at New Delhi in 1963 and the Administrative Radio Conference of the International Telecommunication Union at Geneva in 1959 adopted a recommendation that an Extraordinary Administrative Radio Conference be held in the latter part of 1963 to take up the question of frequency allocation for space telecommunications.

However, in order to get started at once the A. T. & T. Company recently filed applications with the Federal Communications Commission for establishment of experimental active satellite repeaters and a satellite ground terminal at Holmdel, New Jersey for conducting tests of overseas communications to and from points in Western Europe and the United Kingdom. These applications requested frequencies which would be shared with existing services and operations will be properly coordinated in order to avoid interference. It is expected that if these applications are approved soon, testing can commence in about one year. The tests will consist of one-way transmission of television signals and two-way transmission of a small number of simultaneous telephone conversations. If successful, commercial service can be commenced as soon as arrangements can be made for the overseas terminals and the necessary frequency assignments. America can thus lead the way in the provision of this new and potentially useful form of service.

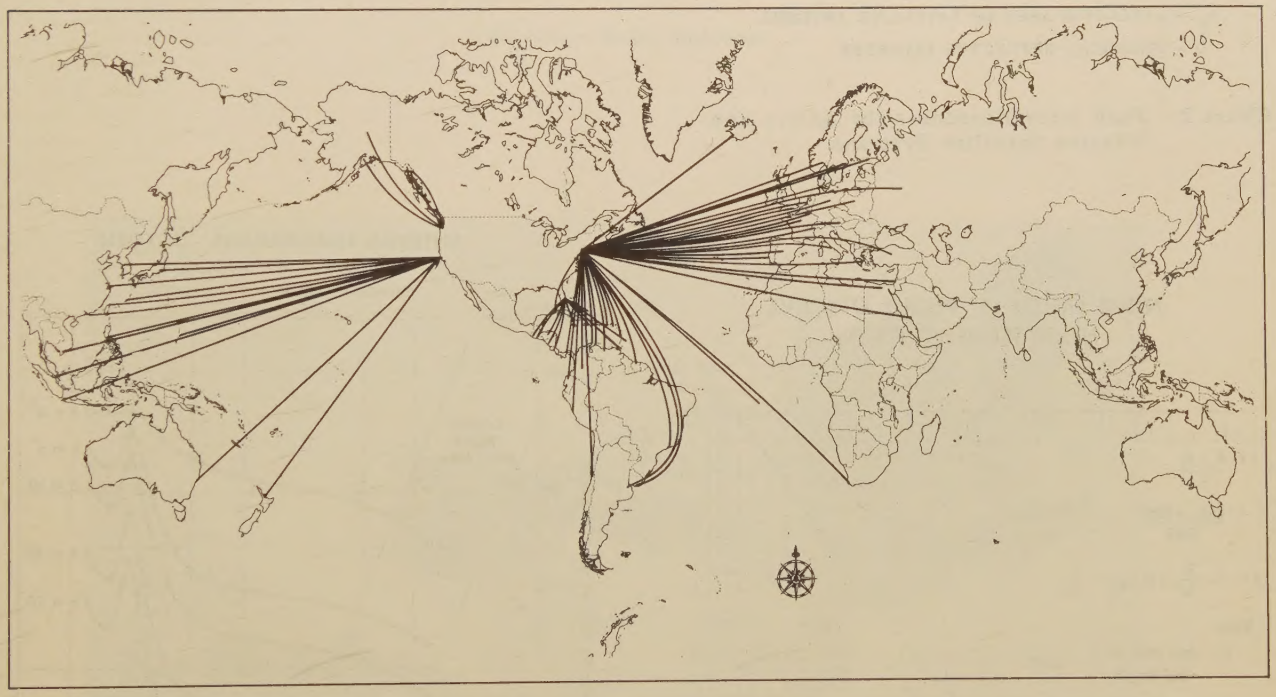


Chart 1 - Bell System Overseas Telephone Service

PATH LOSS FORMULAS

SPHERICAL REFLECTOR SYSTEM

$$L = \frac{P_T}{P_R} = \frac{16\lambda^2 P^4}{A_1 A_2 D^2}$$

ACTIVE SYSTEM

$$L_1 = \frac{P_T}{P_R} = \frac{\lambda^2 P_1^{\,2}}{A_1 A_s}$$

$$L_2 = \frac{P_T}{P_R} = \frac{\lambda^2 P_2^{\,2}}{A_2 A_s}$$

WHERE:

P_T = TRANSMITTER POWER
P_R = RECEIVED POWER
λ = WAVELENGTH
P = GEOMETRIC MEAN SLANT RANGES TO SATELLITE
P_1, P_2 = SLANT RANGES TO SATELLITE
$A_1, {}^2A_2$ = EFFECTIVE AREA OF GROUND STATION ANTENNAS
A_s = EFFECTIVE AREA OF SATELLITE ANTENNA
D = SPHERICAL REFLECTOR DIAMETER

Chart 2 - Path Loss Formulas for Active and Passive Satellite Systems

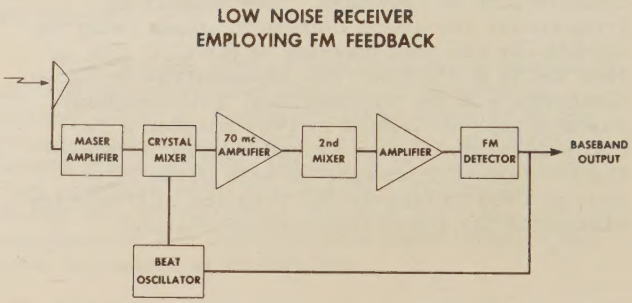


Chart 4 - Effective Noise Temperature vs. Noise Figure

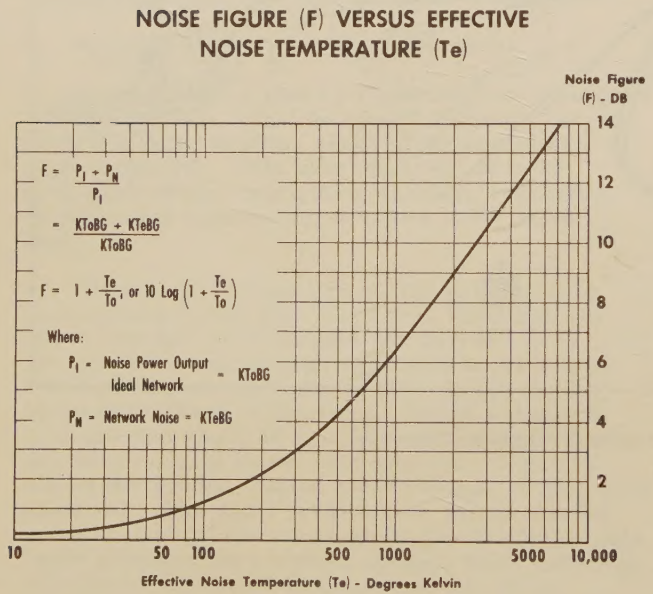


Chart 3 - Block Diagram of FM receiver with Feedback

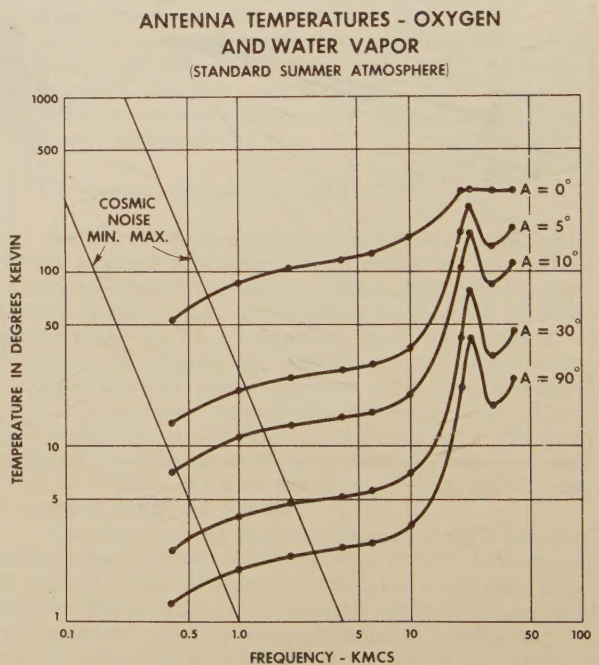


Chart 5 - Antenna Temperatures - Oxygen and Water Vapor

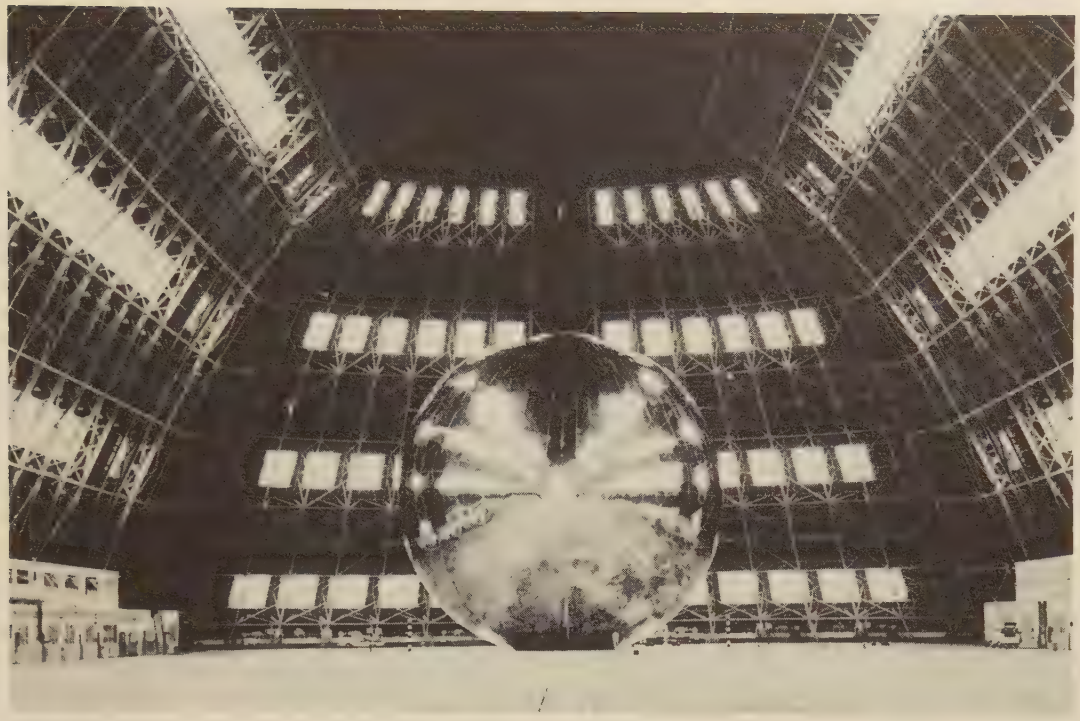


Chart 6 - Echo Balloon

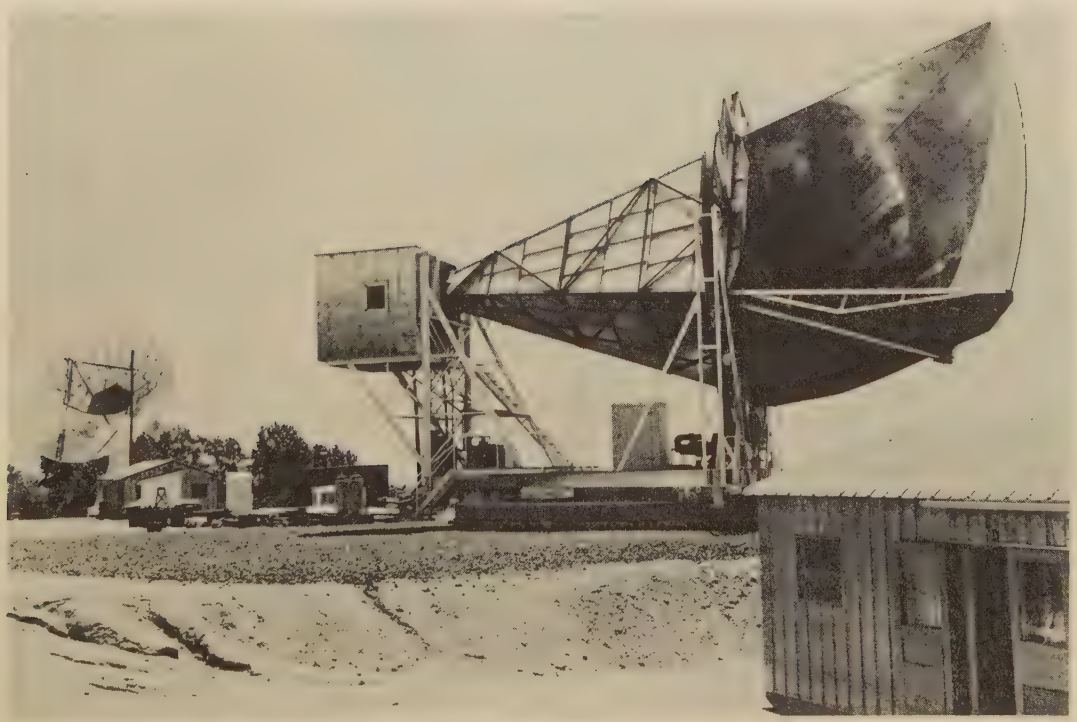


Chart 7 - General View of Holmdel Site

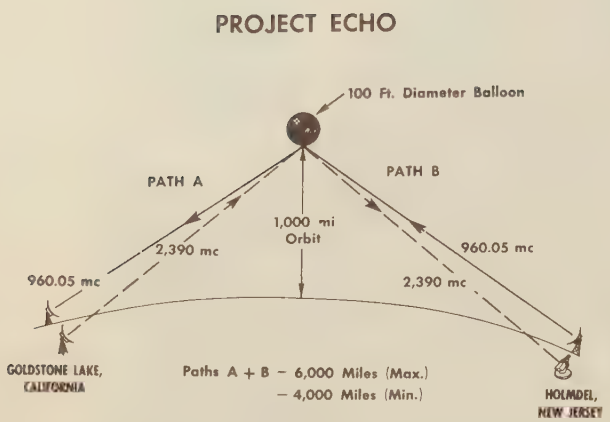


Chart 8 - Illustration of Overall Echo 1 System (showing 2 frequencies)

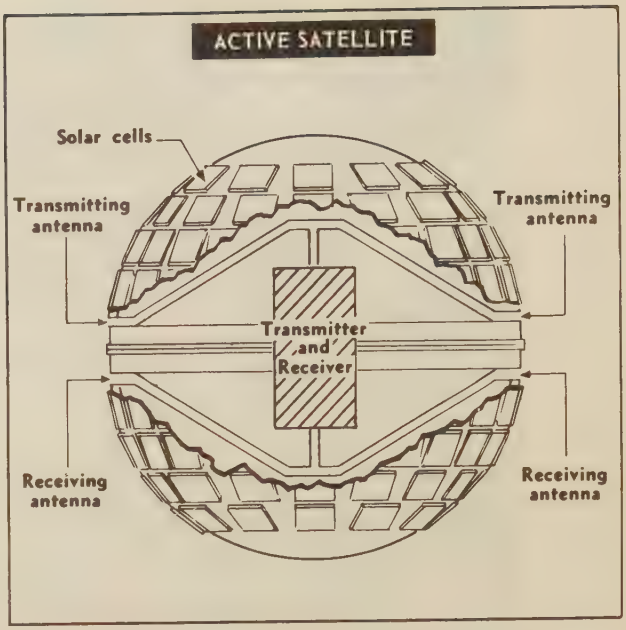


Chart 10 - Illustration of Active Satellite

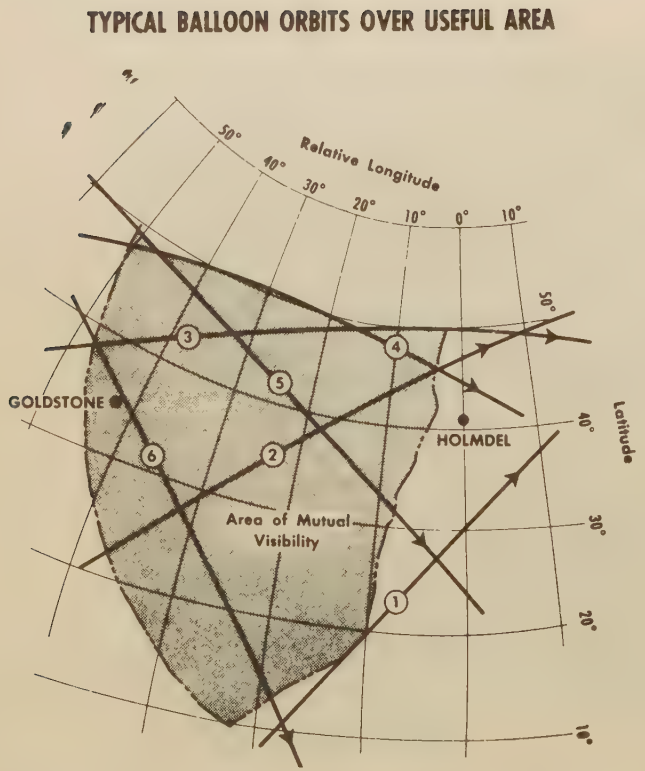
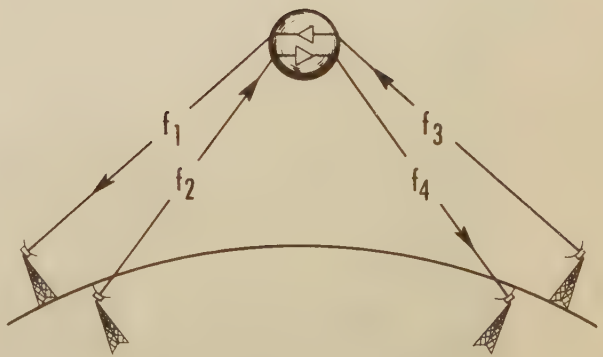


Chart 9 - Area of Mutual Visibility between Holmdel and Goldstone



ACTIVE SATELLITE FREQUENCY PLAN

Chart 11 - Active Satellite Frequency Plan

WORLDWIDE SATELLITE COMMUNICATION NETWORK

Chart 12 - World-Wide System

MOBOTRY: THE NEW ART OF REMOTE HANDLING

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Summary

Equipment to perform a great variety of tasks within hostile environments has been designed and built utilizing well-proven electronic techniques. Such systems perform most of the operations which would be performed manually were it possible for a man to enter the hazardous area. Examples of hostile environments include space, the ocean, nuclear laboratories, and numerous others.

A simple trinary coding command system has proved quite practical and is capable of commanding mobile remote systems having 50 or more degrees of freedom. Conventional closed-circuit television systems may be used for driving and steering remotely-controlled vehicles and for accomplishing manipulative tasks. Two or more such cameras are highly desirable for obtaining good spatial perception.

Examples of remotely-controlled systems for hostile environments include the Hughes Mark II Mobot system for nuclear hot laboratories, the RUM (Remote Underwater Manipulator) built by Scripps Institute of Oceanography for scientific and military operation in the depths of the ocean, and a variety of outdoor remotely-controlled vehicles designed and operated by Engineer Research and Development Laboratory at Fort Belvoir, Virginia, and by Air Force Special Weapons Center in Albuquerque, New Mexico.

Introduction

The electronic techniques which have been developed in recent years, primarily in connection with guided missiles and radar, are finding increasing application in connection with remotely controlled systems for accomplishing physical operations within areas which are uninhabitable due to the presence of a hostile environment. The availability of these remotely-commanded machines can greatly reduce the need for individuals to expose themselves to danger in the course of their daily work.

In some respects, the problem of designing a machine to perform such operations as assembly, disassembly, and the like, in a hazardous area is similar to, but simpler than, the problem of designing a guided missile which can follow a target in spite of any evasive maneuver and finally destroy it.

A specific example of a modern remote handling system is shown in Figure 1. This figure shows the Hughes Mark II Mobot remote handling system, a versatile vehicle intended primarily for use in nuclear hot laboratories. This vehicle with its two arms, each of which has 10 degrees of freedom, and with its two independently movable television "eyes", is an excellent example of the versatility of which modern remote handling systems are capable. With this vehicle in mind as a typical example of a remote handling system, let us explore the fundamental problem of hazardous area operations.

The Hazardous Area Problem

The problem of accomplishing ground support functions in the extremely intense radiation environment which accompanies nuclear propulsion systems is a special case of the more general hazardous area problem. This problem may be approached from a basic theoretical standpoint. Outlined below are a few fundamental points concerning the theory of hazardous area operations.

Figure 2 shows the simple basic geometry of any hazardous area. We see on one side of the illustration an area which is hazardous, meaning simply that it cannot be entered by personnel. The hazard may be nuclear radiation, extremely high or low temperature, extremes of pressure such as are encountered in the depths of the ocean, or extremes of vacuum such as are encountered in space. One can readily visualize a number of additional hazardous areas in which it is preferable not to require personnel to enter.

Within the hazardous area is a function to be performed or a job to be done. This again can encompass the complete gamut of tasks normally performed by human personnel, either with their own hands or with the aid of tools.

Fundamentally, the hazardous area problem requires the design of equipment which will enable the human operator, who is shown in the figure located safely and comfortably outside of the hazardous area, to perform any arbitrary operations within the hazardous area.

The almost infinite scope of possible operational requirements may be made manageable by the realization that all of these have in common the requirement to transfer and re-orient geometrical objects in space. In most cases this must be accomplished in the presence of fixed obstacles over which in general one has no control. Such terms as "manipulation" or "transfer operations" are descriptive of the tasks that human workers perform in assembly, maintenance, installation, and other functions associated with the over-all technology of ground support.

A different way to analyze this problem is to realize that a man, for purposes of this paper, consists of four separate functional systems. These are: his intelligence, his muscles, his senses, and his nerves. His muscles accomplish the manipulative functions mentioned above; his nervous system controls and directs the muscles and reports back via the sensory receptors the status of the objects being handled. Finally, of course, the intelligence gathers and analyzes the data transmitted to it by the sensory nervous system and transmits appropriate commands to the muscles via the nervous system.

The electronic technology available today can quite readily extend the length of the nervous system to any desired distance. The muscular system can be replaced by electronically-controlled actuators (these may be hydraulic, electromechanical, pneumatic, or some combination of these). The sensory system can be extended by means of electronic transducers and data links.

In other words, the intelligence can be separated by any desired distance from the physical work which it is directing and performing by appropriate use of well-proven electronic technology. This is one way of stating the philosophy which guides one in the design of such systems.

So much for the basic outline of the theory and philosophy of fully-remote handling systems. Let us turn now to a more specific look at the engineering of such systems and at their capabilities.

Classification of Remote Handling Systems

As noted above, there are a number of ways which have been developed and which are under study for accomplishing functions in hazardous areas. One method of classification of these systems will be described in this section. There are of course a very large number of bases for classification of remote handling systems. This writer, however, has found that the one presented here is quite useful as a guide for selecting systems in a given situation.

The three classifications are as follows:

1. Direct vision systems
2. Programmed systems
3. Fully-remote systems

Each of these will be briefly described in the following sections.

Direct Vision Systems

This category includes all situations in which it is feasible for the operator to see directly into the hazardous area. The familiar nuclear hot cell is of this type, as is the glove box familiar both to chemical and nuclear technology. Upon a little reflection, one can readily discover a large number of other hazardous area handling methods of this type.

The tools used in direct vision systems are in effect extensions of the human arm. A few examples are the master slave manipulators of nuclear hot cells, the great variety of cranes and hoists employeed in steel mills, foundries, shipyards, and the like, the protective gloves used in connection with glove boxes, and the forceps and tongs which may be employed when the hazard is a relatively mild one. For purposes of this analysis, the electrically-powered general-purpose manipulators which are often found in the larger nuclear hot cells are to be considered as electrical tongs, and serve the same system function as does a mechanical tong.

Direct vision systems are often relatively inexpensive and should be employed whenever the situation permits. However, when one deals with an extremely severe hazard, the cost associated with suitable protective windows and the handling disadvantages associated with the mechanical or electrical tongs may indicate that one of the other systems is to be preferred.

Programmed Systems

In complete contrast to the direct vision systems described in the preceding section, one sometimes finds fully-automatic programmed systems to accomplish a pre-determined sequence of operations in a hazardous area. In this case, the man cannot see into the area nor reach into it; it depends entirely on pre-determined decisions built into the machine itself. One example of such a machine is the reactor refueling devices which can accomplish very complex sequences of mechanical motions in withdrawing a spent reactor fuel rod and replacing it with a fresh one. Such machines in operation will often appear to have a limited degree of intelligence, since their motions are very complex and they may even make very minor pre-determined decisions. In general, they are quite expensive and completely incapable of dealing with any unexpected development. The choice between a programmed system and one of the other types should ideally be made on the basis of careful comparative economical analysis.

Fully-remote Handling Systems

One often hears discussions, which sometimes become acrimonious arguments, concerning "man vs. machine". These arguments usually revolve around a choice of a man or a machine to accomplish a given function in a hazardous environment. In the terms of our current definitions, this is actually a discussion of the relative merits of direct vision systems and programmed systems.

Fortunately, a third alternate is possible which makes fullest use of the unique intelligence and decision-making ability of the human mind without requiring the man himself to be exposed to any hazardous environment, and without requiring the use of massive amounts of shielding or protective materials. These are the systems, of which an example is shown in Figure 1, which may be described as fully-remote electronically-commanded

handling systems. We have coined the term "Mobot systems" as a somewhat less mouth-filling title for this third type of remote handling system.

As mentioned above, the principal purpose of this paper is to present the basic design methods and the present and potential capabilities of Mobot handling systems in context with the alternate methods available for accomplishment of ground support functions within the nuclear environment. The section which follows will present an analysis of the major functional parts of a Mobot handling system.

Engineering Analysis of Fully-Remote (Mobot) Handling Systems

For purposes of analysis and engineering design, it is desirable to divide any fully-remote handling system into six fundamental subsystems. These are:

1. The manipulation subsystem
2. The sensory subsystem
3. The locomotion subsystem
4. The command and data link
5. The control console
6. The power subsystems

Each of these will be discussed briefly below. Figure 3 shows the interrelation among these subsystems for the cable-controlled case; Figure 4, for the radio-controlled case.

When after careful economic and engineering analysis a Mobot system appears preferred in a given situation, the detailed engineering of the system is best carried out by separately attacking the six subsystems just named, and of course integrating these into one effective, reliable, and economic handling system. The following sections will very briefly point out the principal requirements upon the six subsystems and present and future capabilities of each.

The Manipulation Subsystem

One could hardly avoid the use of anthropomorphic terms like "hands" and "arms" to describe those portions of a Mobot system which accomplish the actual manipulations. These devices in general do not resemble the human arm in detail, and indeed as progress is made in this portion of the remote handling art the handlers depart more and more from the geometry of the human arm and hand. The requirements, of course, are difficult to state in detail, but easy to state in general. The manipulating system should be able to grasp an object of arbitrary size, shape, and weight, and to displace and rotate it an arbitrary distance in the presence of arbitrary obstacles. The engineering problem is to design structures of the necessary geometrical versatility which are also mechanically rugged and reliable. One example of an attempt to accomplish great versatility in the geometrical sense is the Hughes Mark II arm shown in Figure 5. Numerous other arm geometries and structures have been developed; there is enormous room for ingenuity and progress in this area.

A truism which seems to be of quite general applicability in manipulation consists of the undesirability of combining extremely complex manipulation with ability to lift very heavy weights. These two requirements are to a very large extent incompatible. Hence, it is usually desirable to furnish separate handling mechanisms for complex and delicate motions from those to simply lift and translate heavy objects. The cross-over point between the two is arbitrary; somewhere between 25 and 100 pounds appears logical, mainly because this is about the place at which the human arm (as a versatile general-purpose manipulator) is replaced by hoists, derricks, or jacks as simple heavy lifters.

A properly engineered handling system can employ the tools of the rigging trade in very much the same way as is done today by human riggers. These tools may in some cases be operated by the electronically-controlled hands. In other cases, they are directly integrated into the command system.

The Sensory Subsystem

This subsystem includes all the information-gathering devices located in and around the hazardous area which collectively inform the human operator of the situation of his Mobot vehicle and enable him to direct and control it. Probably the most important of the senses is vision; this, however, is supplemented by judicious use of other human and non-human senses, such as hearing, touch, temperature, nuclear radiation level, ambient pressure, and a great variety of other measurable physical variables.

The principal requirement of the visual portion of the sensory subsystem of a Mobot remote handling system is to inform the operator of the relative positions in space of the Mobot vehicle itself and of the objects with which it is working. One method of accomplishing this is to employ two or more conventional closed-circuit television camera systems.

Comparison of the information presented to the operator upon the several monitor screens corresponding to the several cameras will enable him to determine, unambiguously, the location in three dimensions of all objects with which he is concerned. To do this requires proper location of the cameras and ability to move and point the cameras to react to differing situations.

To clarify this point somewhat, let us consider one typical and basic situation, as illustrated in Figure 6. The problem is to grasp with the machine's tong an object which is to be transferred to another location. This requires the operator to be aware of the three spatial coordinates separating the tong from the object. Two TV cameras, so located as to observe the working area from mutually orthogonal directions, permit the operator to make this geometrical

calculation.

It is an interesting and perhaps surprising fact that this calculation in solid analytic geometry can be readily learned, and that after a few hours of practice the operator becomes completely unaware of the rather artificial relationship between his two TV pictures and the working scene. A skilled operator obtains from his TV monitors a subjective impression of the three-dimensional orientation of objects in view exactly as vivid and as easy to work with as the subjective impression which we obtain from our own two eyes. This is a dramatic illustration of the extreme flexibility of the human mind.

The use of operator-positioned TV cameras for driving and steering is equally subtle; sufficient experience has now been gained to prove beyond shadow of a doubt that both driving and steering operations and handling and manipulating operations can be accomplished accurately and reliably by a trained operator employing TV systems of the type briefly described herein.

Locomotion

The function of moving the entire Mobot vehicle about can and should be clearly separated from the manipulating function. The locomotion systems to be employed are those which have been developed for many other uses. When circumstances permit, a conventional vehicle chassis adapted for remote control will be employed. This may be either an indoor vehicle, such as the Mobot Mark II vehicle, or any of the familiar on-road or off-road vehicles which are, of course, in very wide use already.

Sometimes it is not feasible to use a wheeled vehicle. In such cases, a three-axis mount, similar to that of a bridge crane, may be employed. When space is limited, a wall- or ceiling-mounted boom may be preferable to a three-axis mounting.

In the undersea environment, one employs floating vessels driven by screw propellers for mobility; this is usually preferable to vehicles which roll or crawl on the ocean bottom. In the space situation, one may employ small rocket motors or compressed-gas jets to obtain mobility in the gravity-free environment.

Thus the design and selection of the locomotion subsystem is accomplished after over-all analysis of the environment by selection from well-proven locomotion methods.

The Command and Data Link

This subsystem is the counterpart of the human nervous system, and is essential for two-way communication to transmit commands from operator to Mobot vehicle and to transmit sensory data as discussed above from vehicle to operator. The data link employs conventional and well-proven techniques adapted from communication and telemetry.

A command system which has worked out quite well in practice is the trinary-coded digital command system shown in Figure 7. This system employs trinary pulses to control the motions of all the moving parts of the Mobot vehicle. A trinary pulse is one which has three possible states, namely, +1, 0, or -1. For Mobot command system purposes, this is preferred to the more familiar binary system, since most elements of the remote system have three normal states rather than two. The normal states are, of course, stationary, moving forward, or moving backward. Almost any moving part has two directions of motion which of course cannot be actuated simultaneously. Therefore, the trinary system is logical and economical.

The fundamental features of this type of command system are shown in Figure 8. In effect, the system accomplishes a one-to-one correspondence between switches on the operator's control console and motions on the remote vehicle. In the multiplexing system, these signals are converted to trinary code and are then commutated and transmitted on a time-sharing basis. At the vehicle, these are de-commutated and directed to the appropriate actuators.

The command information transmitted to the Mobot vehicle is a train of trinary pulses which, 30 times a second, command a new configuration of rest or motion; see Figure 9. Experience has shown this command rate to be completely adequate to give the operator full control of very complex motions and manipulations.

This trinary coding system offers all the advantages of any digital system in that it is relatively invulnerable to fading and distortion in the command link. It is also quite economical of bandwidth. The distance over which the trinary coded commands can be transmitted is essentially unlimited. Conventional radio or telemetry systems can be used for transmitting these command signals. The exact frequency and power to be employed is determined by the distance, the terrain, and the availability of frequencies for the function in question. This is in no wise different from the selection of a two-way radio communication link for any more familiar purpose.

The Control Console

The control console is the man-machine link. It incorporates the display devices by which the Mobot vehicle informs the operator of its location and circumstances and the operating handles for the command switches by which the operator communicates with the machine. One example of such a console is shown in Figure 10. This is the control console for the Mark II Mobot system and illustrates the use of four-position toggle switches for commanding a great variety of motions. This console has proved quite satisfactory in operation. We have also worked with pistol-grip type controls in which a large number of functions are centralized on a single pistol grip capable of a corresponding variety of

motions. A great deal of additional research is required to determine a truly optimal control console configuration with due regard to ease of learning, ease and comfort of operation for long periods, and other factors involving an interrelation of psychology, human factors engineering, and electronic engineering.

Power Subsystems

The power which causes the remote vehicle to move about and to displace objects, as well as the power to operate the sensory and display systems, is perhaps well considered last in the sequence of design. One always finds more than one power subsystem, since the vehicle itself must carry at least auxiliary power on board. In systems which employ a cable for communication between operator and vehicle, this same cable may well be used to transmit electrical prime power. This is almost always a desirable system when circumstances permit its use. Radio control systems, of course, must carry a prime power source on the mobile vehicle. This may be an internal-combustion-engine-driven generator or, in extreme cases, a nuclear power plant. A Mobot engineer will select from proven power technology that combination of prime and secondary power systems which will accomplish his functions most economically in terms of cost, gross weight, and bulk.

Experience with Fully-Remote Handling Systems

A brief summary of experience to date with fully-remote handling systems may clarify and make meaningful the rather theoretical discussion of the preceding sections.

The Hughes Mobot Mark I, which was delivered to Sandia Corporation in the latter part of 1959, has now been in use at that laboratory for over a year. This machine is shown in Figure 11. It is a heavy machine, capable of lifting and handling 150 pounds, and of lifting (but not handling) 1500 pounds. It is a cable-controlled machine for use in a large hot cell and, when used in association with master-slave manipulators, offers very great versatility. It is noteworthy that the net cost of the hot cell making full use of the Mobot concept is very substantially less than that of a comparable hot cell employing direct-vision type manipulation alone.

Another example of a fully-remote handling system for a completely different field of application is shown in Figure 12. This vehicle, referred to as RUM or Remote Underwater Manipulator, was built by Scripps Institute of Oceanography for the Office of Naval Research. This heavy vehicle, equipped with a single planar arm, has demonstrated the feasibility of fully-remote operation on the ocean bottom. A cable reel, which is shown in the figure mounted on the aft end of the vehicle, contains 25,000 feet (5 miles) of coaxial cable. Through this cable is transmitted command information and television signals, as well as the electric power which operates the vehicle.

A third example is the Hughes Mark II Mobot handling system which is shown in Figure 1. Figures 13, 14, and 15 show this system accomplishing several typical handling functions. It has also proved completely feasible to drive and steer this vehicle within the corridors of our laboratories. All of these functions are accomplished completely by electronic command and data communication employing a three-wire cable as the only link joining the remote vehicle to the operator.

Still another example of a partial-remote-commanded system is shown in Figure 16. This is a remotely-controlled earth-moving system operated in an experimental way by the Army Corps of Engineers, Fort Belvoir, Virginia. This machine, of course, does not include the handling function as such, but it does exhibit all the other attributes of a fully-remote handling system and, in spite of its rather primitive viewing methods, has operated satisfactorily.

A remotely-controlled street-sweeper employing television for guiding and steering and a simple frequency coded command system has recently completed successful tests at Air Force Special Weapons Center in Albuquerque.

These examples, plus others which will occur to many readers, have demonstrated the feasibility of fully-remote electronically-commanded handling systems. These systems make possible the accomplishment of a great variety of operations without exposure of personnel to physical hazards. The experience to date indicates fully-remote handling systems to be both psychologically and engineering-wise practical; without doubt the immediate future will see a great deal of activity in this field which will result in systems far advanced in complexity and sophistication from any which have been built to date.

Future Developments

It is possible from the work to date to make some preliminary predictions concerning applications of the remote handling art in the immediate future. These applications follow immediately from a review of the hazardous areas in which, for either military or commercial reasons, one finds it increasingly desirable to enter and perform a variety of operations.

Some of these hazardous areas are the following:
- space
- the depths of the ocean
- nuclear radiation laboratories.

The detailed engineering required to design and construct equipment to survive in each of these environments is of course radically different. In the underwater situation, we are confronted with extreme hydrostatic pressure, with electrolysis which destroys many common structural materials, and with a medium in which electro-magnetic radiation propagates only with difficulty. We learn from those who have built

submarines, oceanographic instruments, Bathyscaphes, and the like, structural and fabrication techniques which will satisfactorily perform in this environment.

In the nuclear environment we may encounter extremely high levels of nuclear radiation which will quickly destroy many materials commonly employed in electronic and optical instruments. We may also encounter contamination which, while not interfering with the operation of equipment, may cause difficulties in servicing and maintaining it. In this context, those who have worked with nuclear reactors and nuclear hot cells are developing techniques for fabrication of reliable equipment for the nuclear environment.

In space we encounter still further environmental problems. For example, most lubricants will perform inadequately, if at all, under conditions of extreme vacuum. Equipment in space may be subject to extreme variations of temperature between its sunward and its shaded sides. Here again, the materials people and the environmental specialists are developing mechanisms and structures which will operate under these extreme conditions.

In view of this situation, it appears logical separately to approach the problems of developing remote handling technology as such, and of engineering equipment for difficult environments. In this manner we will learn how efficiently to engineer remote handling systems to perform any predetermined function or operation; these machines will then be designed in detail by scientists who are specialists in the art of designing against difficult environments. This separation between environmental problems and remote handling problems will result in rapid progress in development of actual useable remote handling systems for all of the hazardous environments mentioned above, and perhaps others.

The development of these fully-remote, electronically-commanded machines will in time completely eliminate the necessity for human workers to be subjected to environmental or physical hazards in the course of their work. This can be viewed as still another contribution of electronic technology to human welfare.

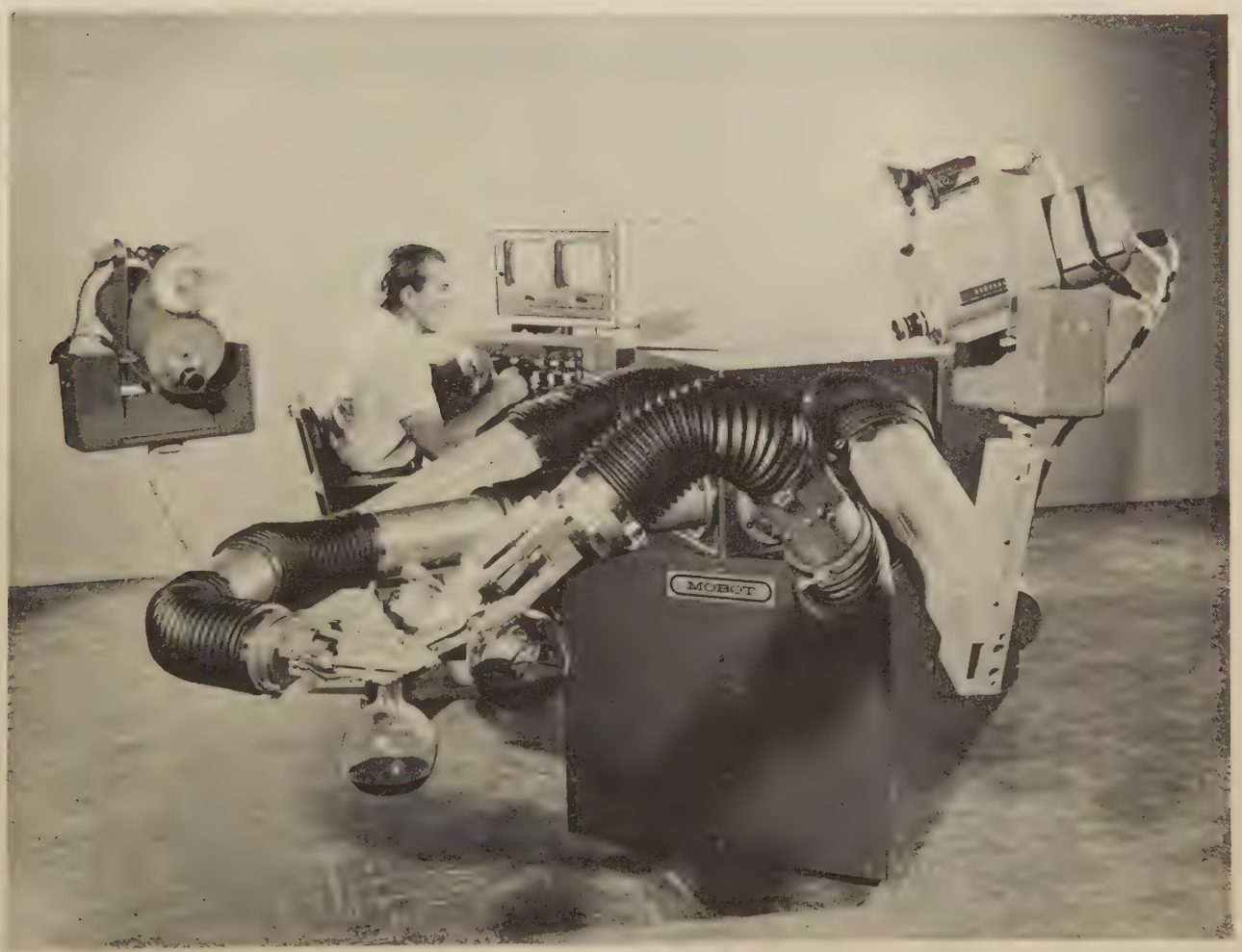


Figure 1 - A typical electronically-commanded remote handling system.

Figure 2 - Generalized remote handling situation

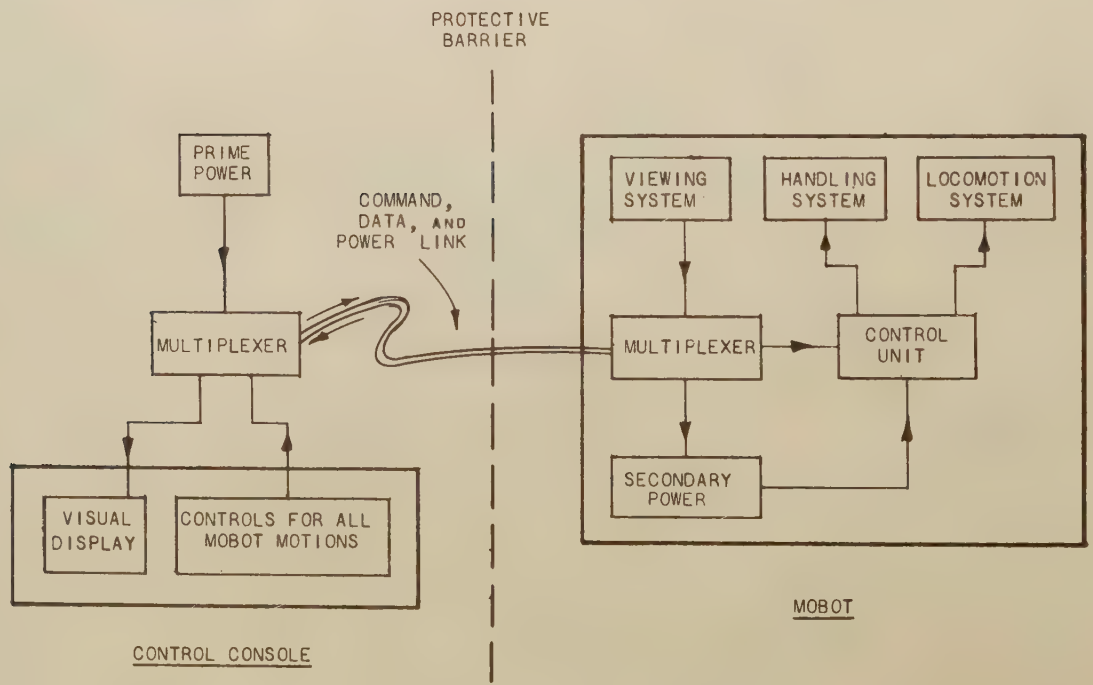


Figure 3 - Generalized block diagram (cable-control type) of remote handling system

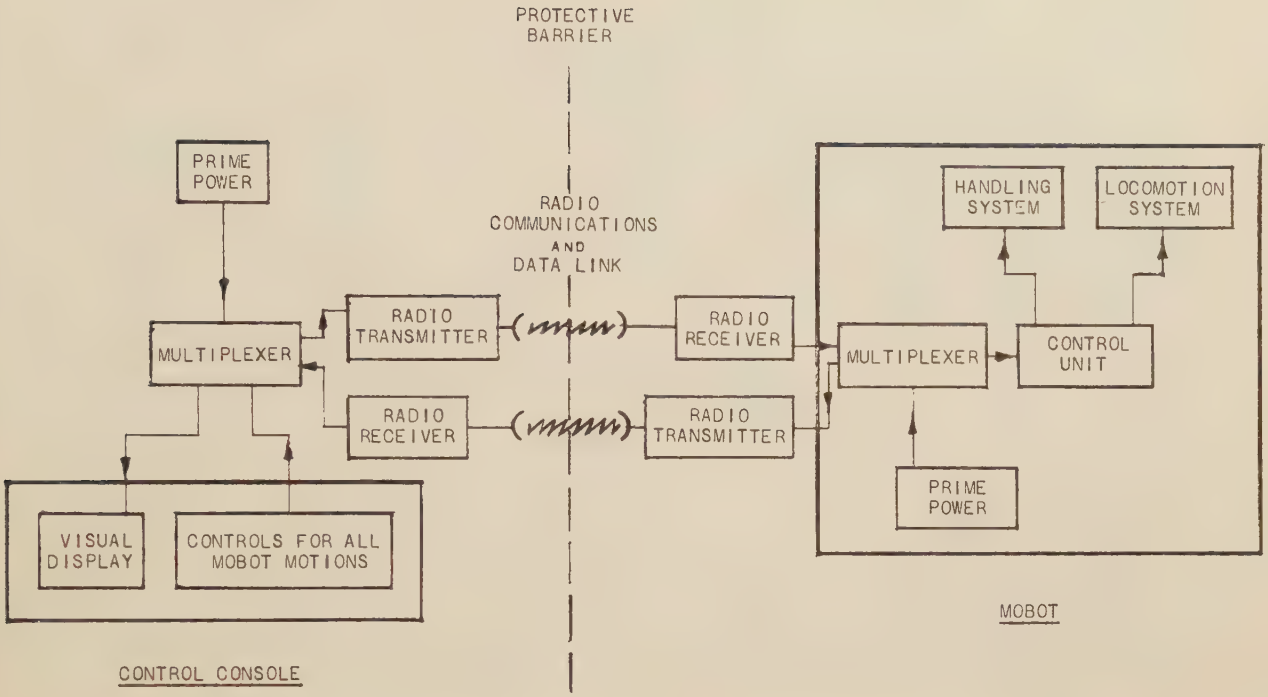


Figure 4 - Generalized block diagram (radio-control type) of remote handling system.

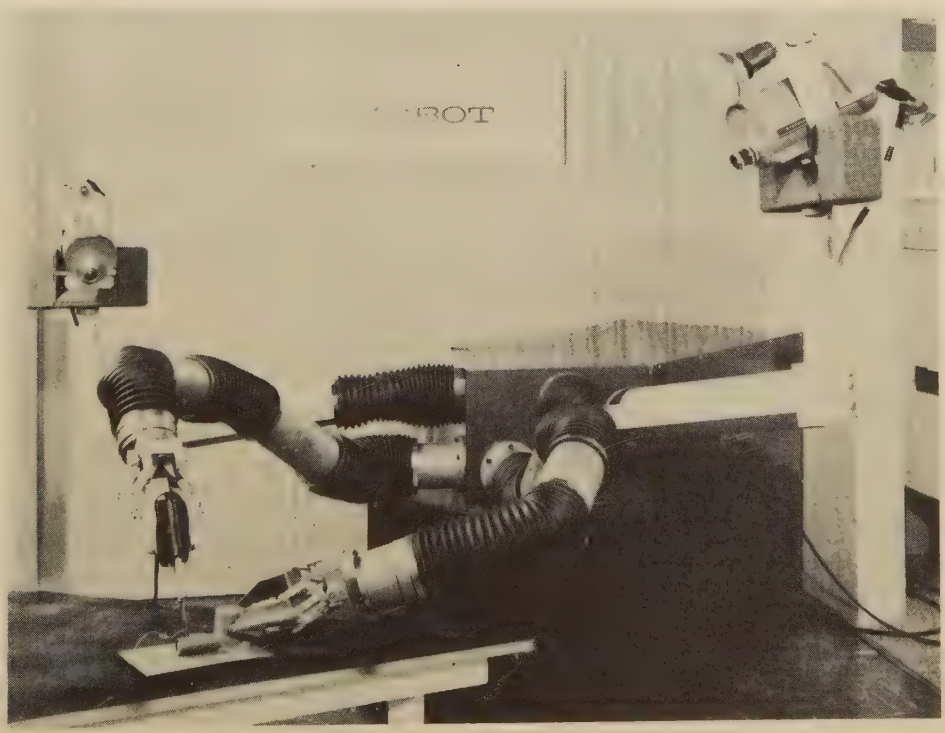


Figure 5 - A Mobot remote handling vehicle using a soldering gun.

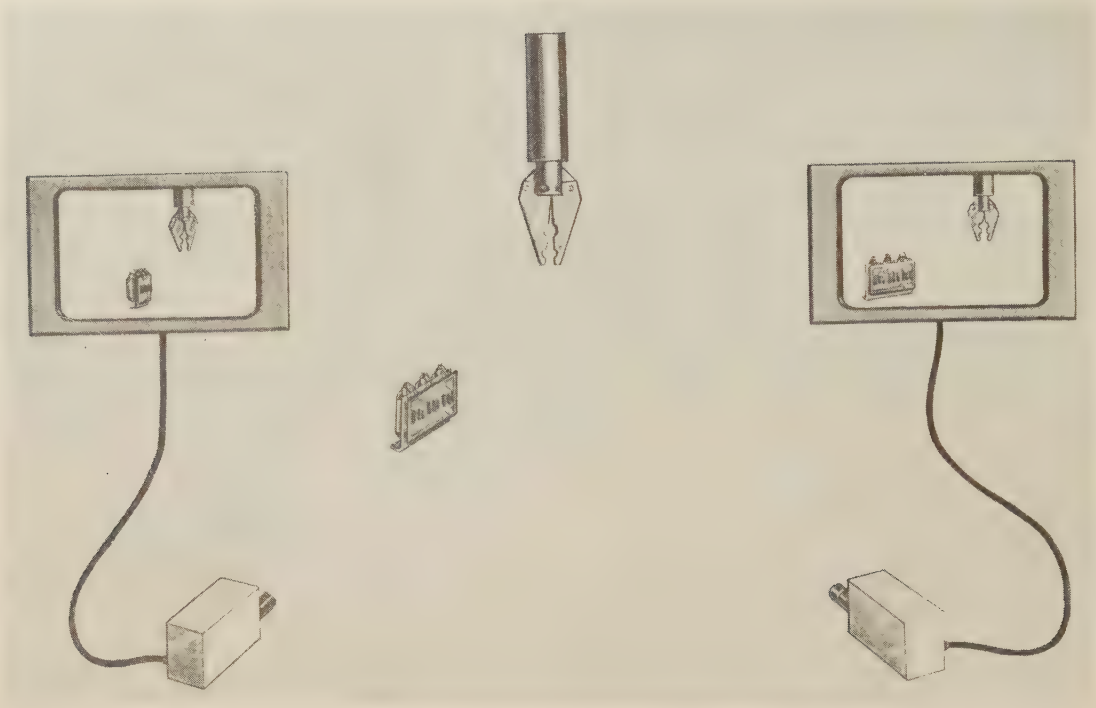


Figure 6 - The two-camera system for obtaining spatial information.

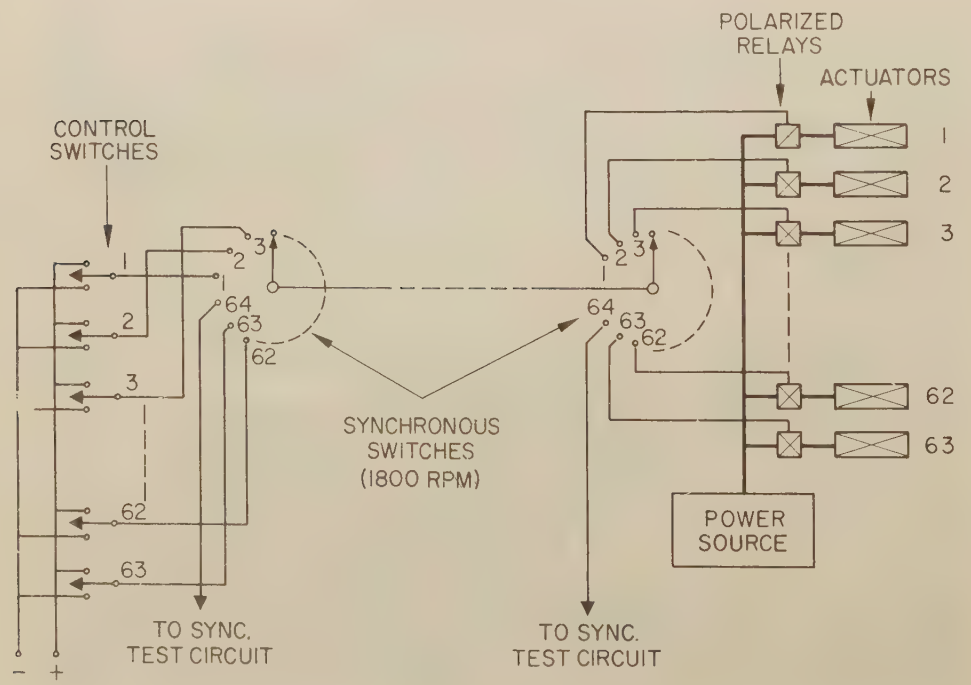


Figure 7 - Trinary coding command system.

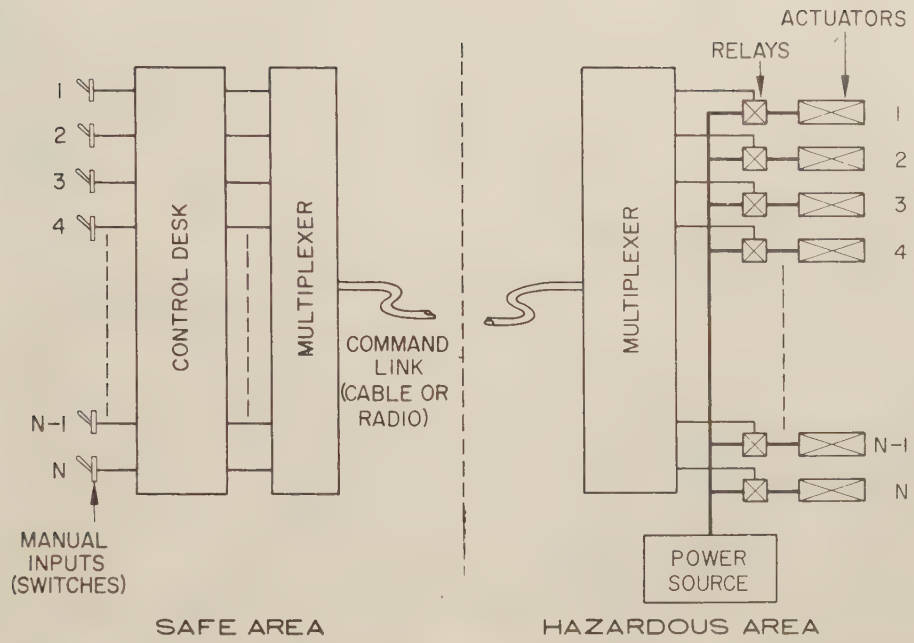
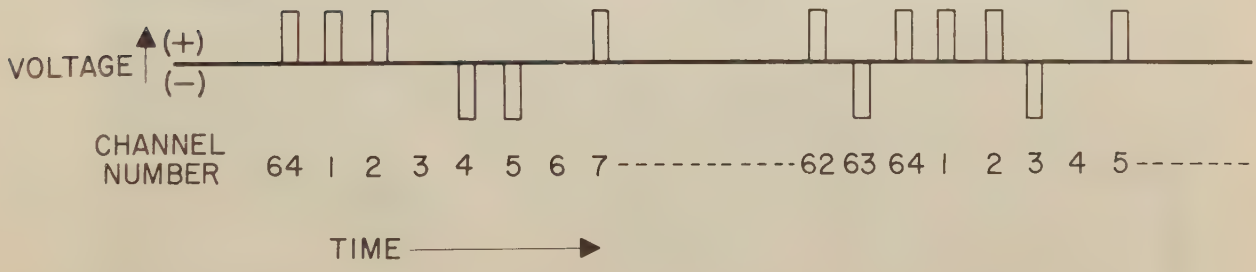


Figure 8 - Command system analysis.



30 63-DIGIT TRINARY "WORDS" ARE TRANSMITTED EACH SECOND
EACH COMMAND CHANNEL IS SAMPLED 30 TIMES PER SECOND
CHANNEL 64 IS USED AS A SYNC. CHECK
BANDWIDTH REQUIRED 15 TO 15,000 CYCLES

Figure 9 - Trinary coded commands.

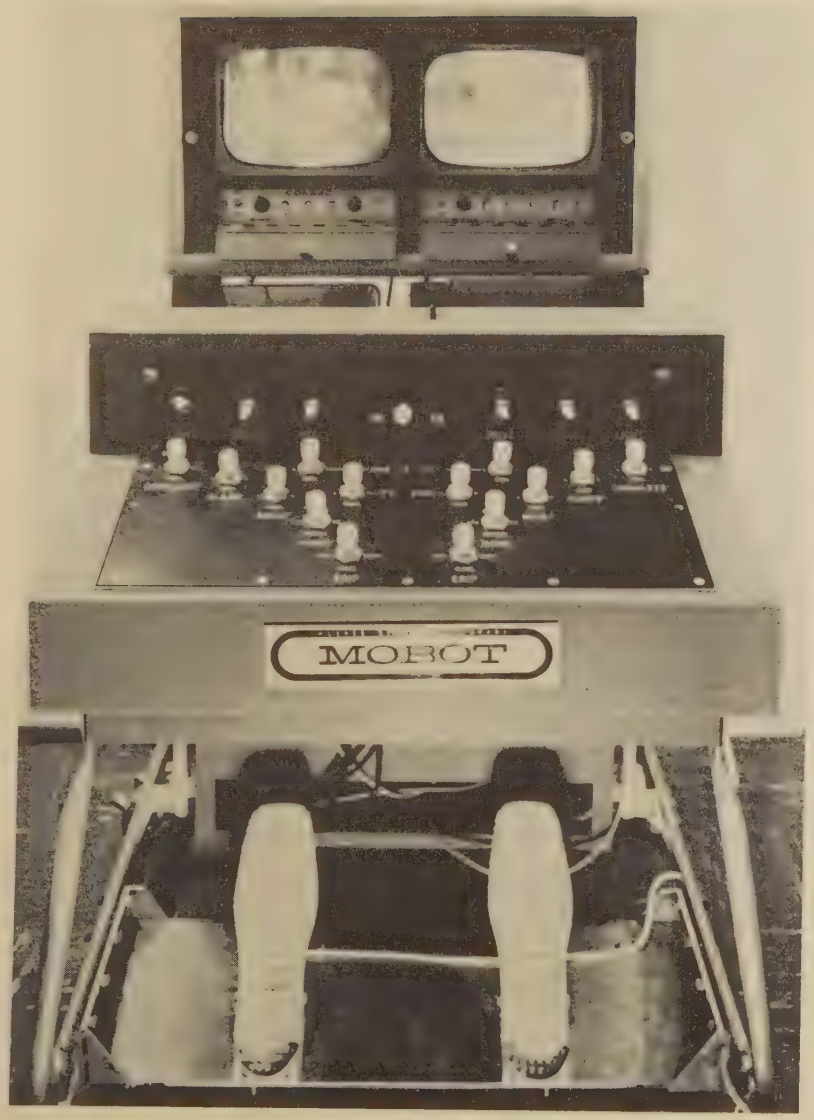


Figure 10 - Mark II control console.

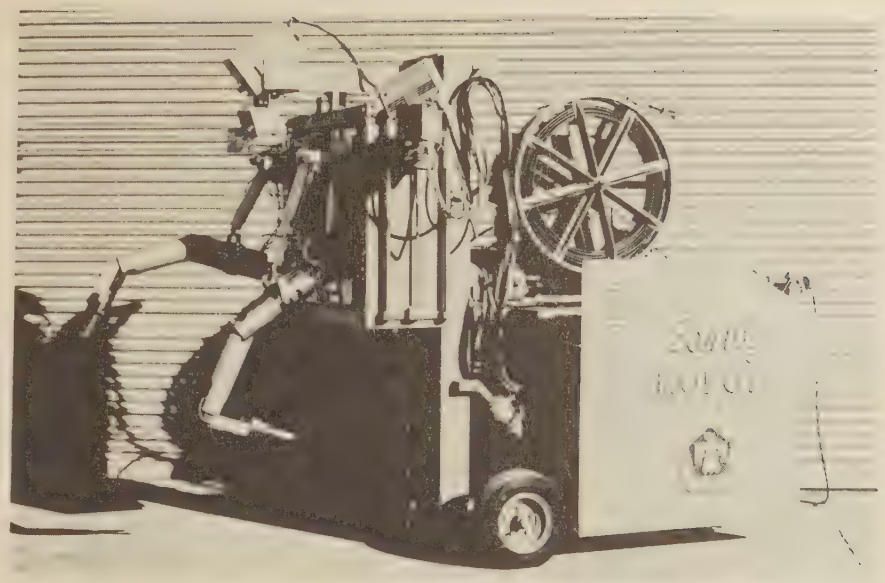


Figure 11 - The Mobot Mark I heavy-duty remote handling system.

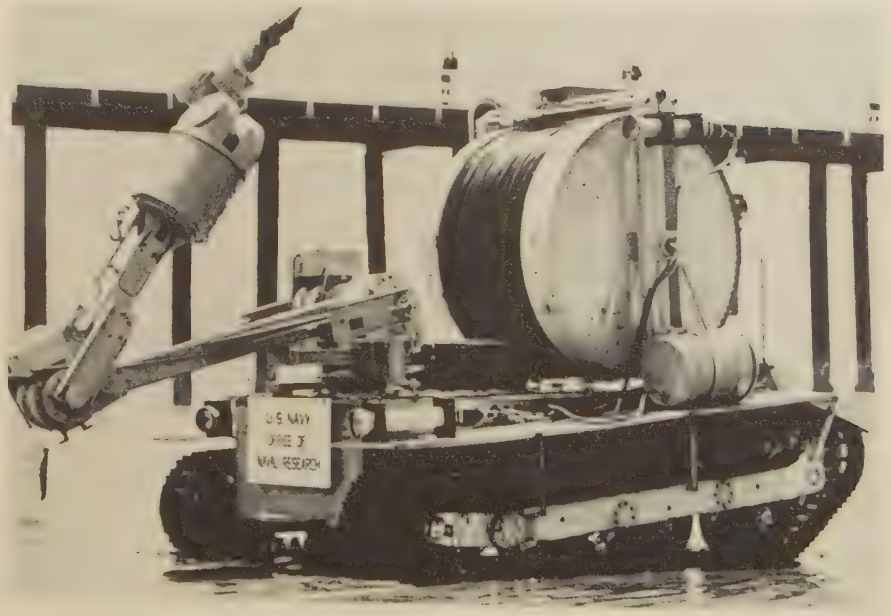


Figure 12 - The RUM, a remotely-controlled underwater handling vehicle.

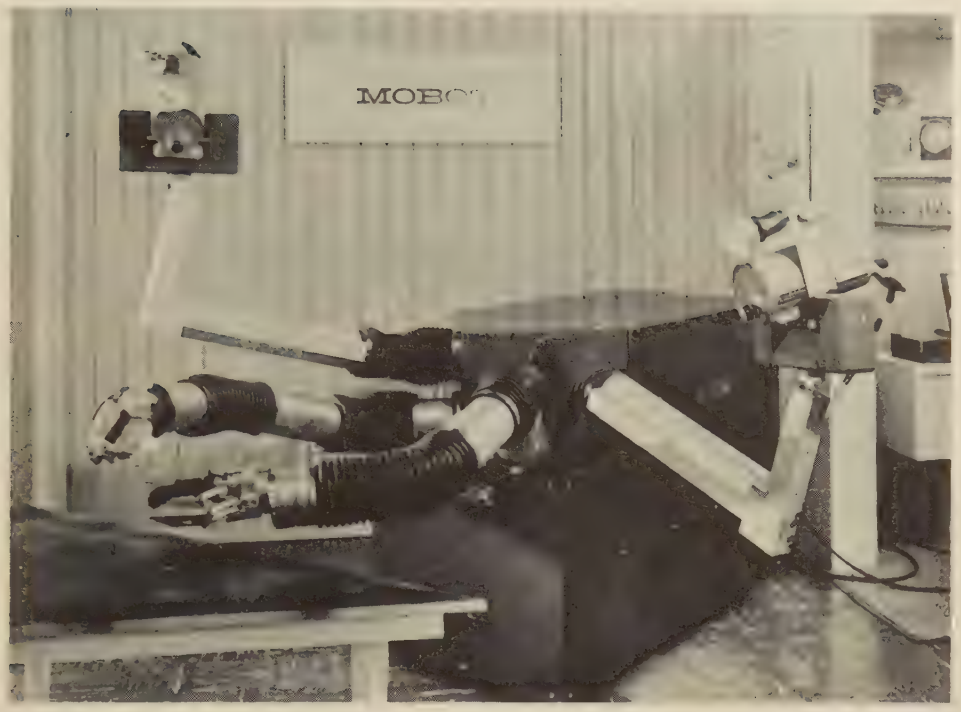


Figure 13 - The Mobot Mark II executes a pouring operation.

Figure 14 - Mobot Mark II operating an electric hand drill.

Figure 15 - Mobot Mark II with 25-pound lead brick at 5 feet arm's length.

Figure 16 - A remotely-controlled bulldozer

AIR LINES RADIO COMMUNICATIONS

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Area Communication Manager, United Airlines,
O'Hare Field, Chicago, Ill.

The first air/ground voice communications was started experimentally by United Air Lines in 1929. It was put into use in 1930. As a result of the air/ground communications and the increase in the air transportation companies, the U.S. government requested that an organization be developed to represent the airline industry to the Federal Communications Commission in the handling of their radio service licensing. Because of this requirement, an organization called Aeronautical Radio Inc. was established in 1930. ARINC represents all of the airlines to the FCC for licensing purposes and frequency assignments. Each airline member owns stock in ARINC. It is a non-profit organization, incorporated in Delaware.

First attempts at air/ground voice communications were made in the high frequency radio range using 3mc and 5mc frequencies. These frequencies in this general range were used from 1930 to after World War II. There are a few other international frequencies such as 8mc and 12mc but basically, in this country the 3 and 5mc sufficed. Our first VHF communications was installed in 1944 and, for the most part, were local control stations only. These were installed for the purpose of determining the economic and coverage status in this type of equipment.

Later it was decided to try connecting several of these stations together by land line, and we gave this the name "VHF network." The first of these was installed on an experimental basis between Chicago and Pittsburgh. AT&T supplied the connecting control lines between the airline owned ground stations. These tests proved successful. The first VHF network between Chicago and Pittsburgh was discontinued, however, for economic reasons only. This was in the area of 1946-7, immediately after the war and there was some recession business-wise. It was re-established again in 1950, operated successfully and other networks were installed system-wide.

To explain the operation of our VHF network, we would have three or four ground stations between an area such as Chicago to Cleveland, connected together with AT&T control lines. The receiver picking up the signal from the aircraft would disable its associated transmitter, send the signal along the control line to the operators located at the control points (in this case Chicago and Cleveland) and would activate the other transmitters for rebroadcast purposes. In this manner, a trip just leaving Chicago could hear a trip reporting just off Cleveland because he would hear this through the rebroadcast facility of the transmitter located in Chicago. With multiple ground stations coming on at the same time, it was necessary to offset the transmitter frequency by a plus or minus 10kc with the third one being right on frequency.

With the advent of high altitude flights hetrodyning became a serious problem even with the 10kc frequency separation, primarily because oscillator stability could not be maintained at the exact frequency. To overcome this problem an oscillator was developed by our engineers which could hold .00003% of the crystal frequency over a wide range of temperatures. We then found that when more than three transmitters were connected along a network, it was necessary to further offset, or subchannel, the transmitter frequency by the plus or minus 10kc plus or minus 60 cycles. This was to prevent speech break up which we encountered without this additional 60 cycle offset. In addition, the aircraft receivers had to be modified to help eliminate further hetrodyning. Someone will ask "why didn't we use FM". The reasons are as follows: First, available equipment at that time was AM. Secondly, it was necessary for the ground operator to be able to tell when more than one signal was on at a time. With FM, you do not get sufficient beat to generate the kind of tone required for this operation, even though FM does hetrodyne to some extent. The ramp radio facilities which you have already seen are FM and you may be interested to know that many of the same problems were encountered here as with the original AM networks, but a little more on this later.

Why VHF? In the 1947 Atlantic City Radio Conference it was agreed that VHF could be used over land without much difficulty. Over water, however, (international for our purposes) it would not work satisfactorily because of it's limited range. Since high frequency spectrum assignments were greatly overloaded, it was decided to move towards VHF coverage domestically for air/ground communications. In 1950, one-half of all high frequency assignments were released and VHF used in their stead. I understand there will be another radio conference similar to the Atlantic City one some time in 1964. It is expected that high frequency useage will be further reduced at that time, and that additional VHF assignments will be used to provide over land coverage.

At the present time, Russia wants more high frequencies for their aviation industry. We don't believe they need it, but our argument is weak when we haven't eliminated it completely in our own country.

Where is VHF network coverage headed? First it started with a little bit of operational control. In other words, air/ground contact for company business purposes only. Then traffic control direct from the aircraft to the controller and third, our operational traffic up trend. At the very beginning the operational traffic up trend was not expected, however, aircraft speed created a need for a faster means to obtain decisions for business reasons, and this item is increasing as we get faster and faster aircraft in the air. For example, our jet aircraft carries just enough fuel to make the flight intended plus a reserve for alternate field operations. When weather conditions set in, and it is necessary for one of our flights to hold, he can hold for only a specific length of time and then must have a decision as to what alternate he will use. These alternates must be coordinated with the ground handling facilities for buses, hotel accomodations, meals, etc. For example, our operations dispatch office located in Denver for the long-range flights can pick up their telephone, talk to one of our aircraft just off New York on VHF, limiting that conversation to that segment of the VHF net from New York west to about Erie, work out details with the pilot long before he reaches, let us say, San Francisco. This is done through the use of present private line telephone facilities connected through Arinc stations and reconnected by Arinc to the proper VHF network where the flight can be reached. Since the aircraft spend a large part of their time on direct pilot-controller frequencies, one wonders how we can attract or call this pilot without getting on the ATC channels. This problem has been answered with equipment called Selcal. You merely set up the code for that particular airplane, press the button and Selcal turns on a light and rings a bell in the cockpit. The captain will then select his company VHF network and answer Selcal.

In May 1953 our ramp activity at airports was sufficient to require the use of radio contact between supervisors on the ramp and the coordinator inside. UAL first used Motorola Pack-Sets on a frequency of 42.98 mc and tests were conducted in Chicago in May 1954; Denver, in November 1954; San Francisco, in November 1954. The first complete system of ramp radio service was installed in Los Angeles on January 11, 1955, and in Chicago on January 21, 1955. Both services were leased from the local telephone and telegraph company.

Because of frequency congestion we continued a search for smaller lighter equipment and equipment that would operate in the 460mc citizen's band. In December 1954 a company known as Radio Specialists Company in Denver was asked to produce a low-power, light weight, two-way citizen's band radio. The final outcome is the Tiny Talkie you saw in use this evening. They weigh about four pounds each with batteries. Someone will ask why the citizen's band on 460? As airports became larger and larger, the industrial frequencies such as 42.98 became overly congested for our use. In addition, it was a requirement that our equipment work from within the aircraft. 42.98 and other industrial frequencies will not do this satisfactorily. As a result of our experimenting and other airline requirements, a new Air Terminal Radio Service band is coming into realization. This will consist of 20 channels presumably with 25kc spacing and will be made up of two bands of 10 channels each to allow double-channel simplex operation.

I might add that in 1956 additional installations were made on 42.98mc at Honolulu, Seattle, Portland, and Omaha. Our first citizen's band on 460-470mcs was installed in Idlewild in November 1957. It was necessary to make this the first installation because of the extreme interference on the other frequencies for which we were licensed. In 1956 the consent decree was interpreted to mean the telephone companies must stop the leasing of private radio service by January 21, 1961. This was by court action of the Attorney General against AT&T, not by anything from the FCC. As a result, UAL was required to obtain service elsewhere. We were able, through the help of Radio Specialists in Denver, to lease G. E. Base Stations and by this time they had a sufficient supply of Tiny Talkies and made available to us a leasing arrangement, including maintenance, that was quite acceptable. This type of service was not available through any other company with equipment in this range. On January 21, 1961 all previously licensed telephone company installations were replaced by the new lease arrangement from RSC.

We have other VHF uses such as aircraft tow tug radios. These are on the control tower's ground control frequencies and is used primarily in towing aircraft across taxi ways and active runways. There is also a necessity, when towing jet aircraft, to communicate between the tow tugs and the cockpit for the coordination of brakes and other activities, Presently there are kits being developed and added to our tow tug equipment to permit contact between the cockpit and the tow tugs. Whether this is an intercom system or radio, I cannot answer at this time.

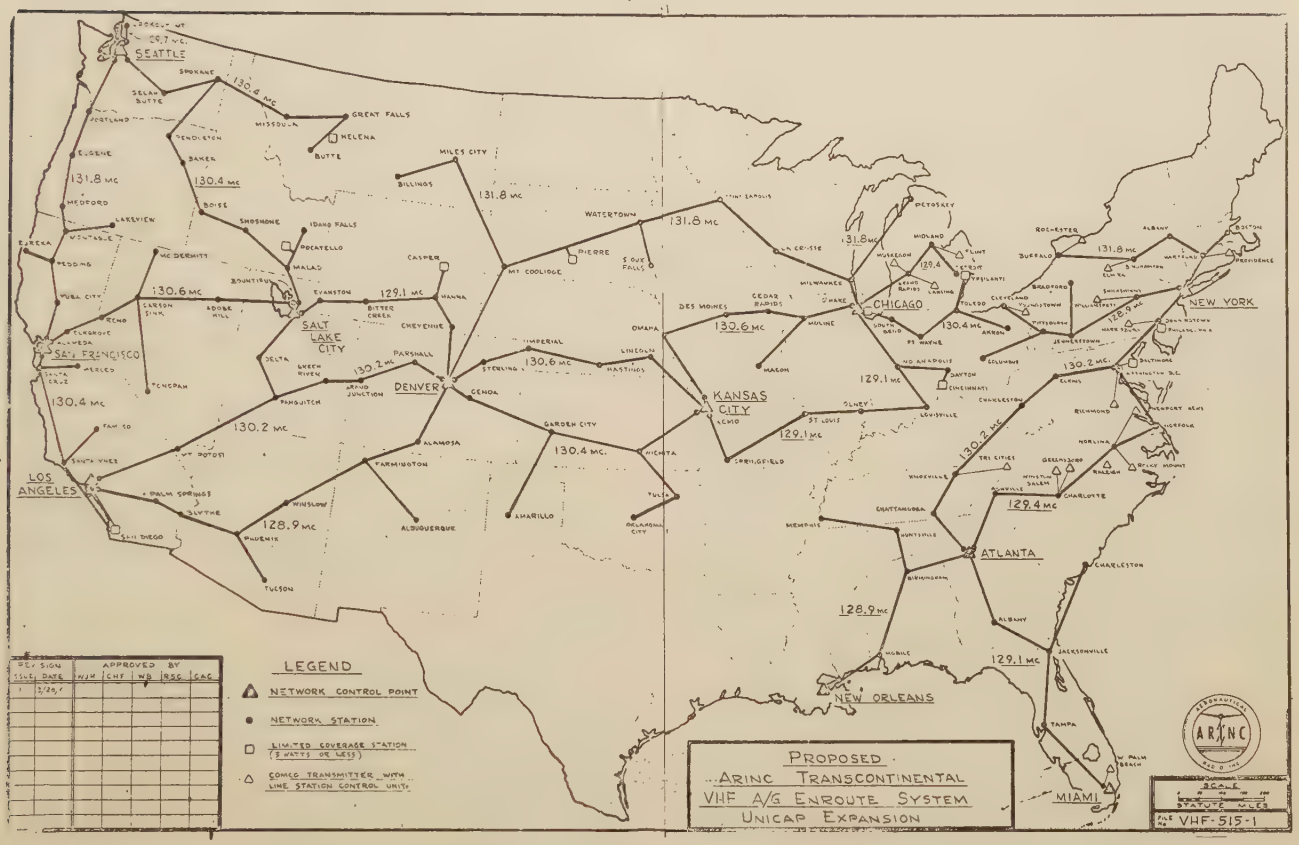
Our ramp noise, as you probably noted, requires noise cancelling microphones and a special type of earphone. This applies to both tow tug and ramp radio services because of the high jet noise level.

In the next 7-10 years new equipment will be developed. We hope a type that will be much smaller and much lighter in weight. For our purpose it should be in the general vicinity of the 460mc band since that is where the new Air Terminal Radio Service Band will be located. Separate transmitter and receiver units are a good possibility and it is expected that some type of helmet installation will come into being for use outside on the ramp where the earphones can be the sound-proof type necessary for personnel working around jet

aircraft. Other packaging of these units if they are small enough could be arranged for by special pockets in uniforms, etc.

At the present time, UAL at O'Hare is using 12 Tiny Talkies, 1 Base Station, 7 Mobile Units, and 5 Tow Tug installation. What's for the future? In 1962 we plan to expand the O'Hare operation to 24 Tiny Talkies, 2 Base Stations, and 26 Mobile Units, including Tow Tugs.

In conclusion, I would like to add that it is absolutely necessary we develop new, light weight, transistorized units. This type of equipment is in the process of being engineered by RSC. The weight is expected to be one-half of our present facilitiy and will probably consist of one type battery in the alkaline category, since this seems to operate more efficiently under conditions of heat and cold. For example, the new engineering model had the transmitter on for 88 minutes without battery decline.



THIN ROUTE TROPO
A NEW APPROACH TO LONG RANGE COMMUNICATIONS

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Summary

This new system of communications makes use of tropospheric scatter for the transmission of digital information over long distances more reliably than high frequency radio; more economically than wire; less vulnerably than microwave or VHF and cheaper than conventional tropospheric scatter systems. Using only a narrow-band width, it can be used for transmission of data (teletype, telemetry, canned messages, facimile, etc.) over distances of upwards to 500 miles, using relatively low power transmitters and simple antenna systems. It will provide a useful link in the radio communication systems for many government agencies, both military and non-defense. While limited to these under the present regulations, it has potential for use for commercial applications in the future.

Introduction

Today messages are winging their way over a 700 mile single hop over Artic wastes from Cape Dyer to Greenland with a 99.9% reliability. General Electric was the prime contractor for design and development of the AN/FRC-47 tropospheric scatter system for the Air Force. It provides 24 voice channels on the longest tropospheric scatter system in the world. A system like this uses vast antennas (120 feet high) with gains of 40 db, (Figure 1) high power transmitters (50 kilowatts) with band widths of 100 Kc. (Figure 2)

You may say, "What bearing has this on Mobile Radio communications in the United States?" A great deal, for out of this development came the concept of a new tool for radio communication, Thin Route Tropo-Scatter Communication System. We call it Thin Route Tropo for short, or TRT. It will provide highly reliable point-to-point digital communications for distances from line of sight to upward of 500 miles, using relatively low powered transmitters and moderate size antennas. The Thin Route concept is based upon relatively narrow RF band widths.

Basic Concept of TRT

In the past, in Mobile Radio, we have been accustomed to thinking of the voice channel as the basic element of communication. TRT is based on the very different concept; that of a digital communication channel as the basic element.

Voice communication is inefficient in time and band width compared to digital communication. For example, 100 word per minute teletype communications can be carried with a band width of 120 to 150 cps, whereas a voice channel, in which it is not possible to sustain this rate for any length of time, requires 2,000 to 3,000 cps.

In the future we can expect to see digitalized communications, more and more, taking the place of voice communications. This can be in the form of teletype, data transmission, canned messages, by which we mean visual display of predetermined words, or messages selected by digital code, and eventually digital speech. There is a great deal of work being done in the area of digital speech and we can expect results in the not too distant future.

TRT can be used for simplex, duplex, or multi-directional transmission of initially up to 6 conventional 100-word-per-minute teletype channels (800 cps total band width); hence, the name "Thin Route" as in contrast to conventional multi-channel communication systems requiring up to 6 megacycles band width or more.

Design Considerations

In designing communication systems you trade certain variables, antenna gain, RF power output, band widths and possibly, diversity arrangements to achieve satisfactory operation over a desired path with a given attenuation.

Bandwidth

Since the ultimate sensitivity of any receiver is determined by how much noise a signal must overcome within the receiver itself, the useful sensitivity then is in inverse proportion to both the noise figure and receiver band width. By using the narrow band width possible with digital communication rather than the much wider band width required for even a single channel of voice, TRT can be used over tropospheric scatter paths of high attenuation with moderate RF power levels.

The TRT receiver has a sensitivity of -177 dbw for 0 db S/N in 130 cps band width. This is 40 to 50 db more sensitive than conventional FM tropo equipment. To bracket this a little better, a conventional 450 Mc FM mobile receiver would be about -140 dbw for a minimum useable signal and a

typical satellite receiver with about 10 cps band width, about -190 dbw.

A 32 db difference between TRT and conventional tropo corresponds to a power ratio of 1600 to 1. This can be translated into extra range, reliability, antenna and transmitter power reduction. For example, there is 33 db between our 25 watt transmitter and a 50 kilowatt power amplifier. There is 24 db difference between a TRT 3 foot by 4 foot antenna and the 120 foot AN/FRC-47 antenna.

Diversity Reception

To reduce the margin necessary to protect against loss of minimum acceptable signal to noise ratio, and therefore power required, diversity reception can be used. Space diversity, frequency diversity, time diversity and angle diversity (multiple feeds on one dish) are all applicable to TRT.

RF Frequency

Tropospheric scatter effects can be used over a range between 250 and 2,000 Mc. For TRT we have chosen the 450 Mc range, after weighing the various systems considerations. Some of these were:

1. For a given antenna array, you get better performance at the low frequencies. For example; data published by the Bureau of Standards shows that for a 220 mile path for a Yagi antenna, the lower the frequency the less power is required. Parabolic dishes, on the other hand, show optimums around 450 Mc and 750 Mc respectively, with relatively mild slopes in between.

2. Frequency stability requirements are easier at the lower frequencies.

3. On very long paths, tropospheric scatter propagation favors the lower frequencies.

4. Equipment is more available and less expensive at lower frequencies. This is particularly true of transmitters.

5. On very short paths the diffraction made is of interest in case of very poor horizons and this calls for the lower frequencies.

6. For mountainous areas where knife-edge enhancement is possible, lower frequencies are preferable.

Trial System

General Electric has had a Thin Route Tropo system operating between its Communication Products Department's plant in Lynchburg, Virginia and Washington, D.C. since January, 1960. This circuit is a 152 statue mile, one hop tropospheric scatter system. The terrain, is anything but plane earth, as there are a number of ridges between the terminals.

Equipment

On the prototype installation the 250 watt transmitter delivers 150 watts of RF to the antenna. The antenna is mounted as an existing mast at a height 125 feet from the ground.

The frequency source is the high stability oscillator currently used on the AN/FRC-47. This oscillator has a short term stability at 12.5 megacycles of 1 part in 100 million per day. This high degree of stability and day to day maintenance eliminates the need of AFC on the receiver. Future equipment can be furnished with a long term AFC to assure unattended operation over long periods of time.

Dual diversity reception is used with two antennas 200 feet apart. Figure 3 shows one of the antennas used at the Lynchburg end. It is a Yagi array, six by four feet, weighing less than 50 lbs., mounted on a mast on the roof of the plant, 90 feet above the ground level.

In the dual diversity receiving equipment at Lynchburg receiver front ends provide a 5 db noise figure. This gives a zero db S/N at -171 dbw. The output of the receiver is fed into the Kleinschmidt printer.

Performance

Path Attenuation. The profile map (Figure 4) shows that the transmitting antenna is about 500 feet above sea level and the receiving antenna about 940 feet, even without obstructions conventional line of sight communications would be impossible.

Let us look at the actual path data.

Lynchburg-Washington Path Calculation

Losses

Path - 152 statute miles
Path Loss - 99% of the time on an hourly basis the loss will be less than 205 db
Line Loss - 4.5 db
Reliability Correction - 9.5 db (This insures that at any time there is a 95% probability the loss will be less than 219 db)

Total Loss - 219 db

Gains

Antennas - 36 db
Transmitter - 24.75 db
Total Gain - 60.75 db

Performance

Total Loss - 219.00 db
Total Gain - 60.75 db

158.25 db

Receiver zero db S/N at -171 dbw so receiver S/N is 12.75 db (substantiated by actual operation)

The maximum measured winter scatter loss is 219 db or less 99% of the time. From this calculation, we see that the receiver can maintain an average signal to noise ratio of better than 12 db. These figures have been confirmed by operational tests.

In this test circuit, 60 word-per-minute, start-stop teletype is used; as Figure 5 shows, a character error rate of better than 0.12% for 99% of the time was obtained, which is good teletype performance. Note that no diversity represents a 13 db loss.

Test Results. A typical test run showed approximately 5 character errors on the page out of 3,000. This is a character error rate of approximately 1 in 500, and a bit error rate of 1 in 3,500. The particular sheet of copy from which this data is taken was chosen as relatively poor copy and illustrated the types of errors which tended to occur. A study of the errors showed that errors were relatively few and when an error occurred, a message could be retransmitted almost immediately thereafter and arrive without errors. This is not true of some types of systems (such as high frequency) which are subject to outage periods of days at a time.

TRT Equipment

Thin Route Tropo equipment is being built on a building-block basis, fixed plant, van or helicopter hut mounted terminals form the basic package. We intend to expand the basic line into the vehicular and mobile field and it is entirely feasible that a terminal can be carried by one man.

Specifications

Here are the specifications for TRT equipment.

General	Descriptive Specifications
Type Number:	YA-1-A
Frequency Range:	400-470 Mc
Bandwidth at Carrier Frequency:	Up to 800 cps (for 4 RTTY channels), selected by means of plug-in filters, for Time Division System. 3,000 cps for voice, Frequency Division System, or high speed data.
Modulation:	Binary for data, analog for voice.
Operation:	Simplex, duplex.
Frequency Stability:	1 in 10^8 per minute, 5 in 10^8 per day.
Type of Operation:	Continuous (Unattended, 10,000 hr. expected tube life).
Service Conditions:	Designed to withstand, without degradation in performance or damage:
Ambient Temperature	Operating - - 20°C to + 60°C Non-operating - - 60°C to + 70°C
	No readjustment is required over changes as great as 40°C ambient.
Humidity	Up to 95% operating and non-operating.

Transmitter

Power Outputs:	25,500 or 1,000 watts (Dependent upon combination of building blocks).
Power Input:	117 VAC ± 10%, 50 or 60 cps single phase or 230 VAC ± 10%, 50 or 60 cps single phase.
Power Demand:	25 watt transmitter - 350 watts 500 watt transmitter - 1900 watts 1000 watt transmitter - 3800 watts
Cooling:	Forced air.
Space Requirement:	One 19" rack houses a complete 25 watt exciter and a 500 watt P.A. (Maximum floor space 18" x 21").
Output Impedance:	50 ohms.

Receivers

Power Input:	117 VAC ± 10%, 50 or 60 cps, single phase or 230 VAC ± 10%, 50 or 60 cps, single phase.

Receivers	Descriptive Specifications
Power Demand:	Dual diversity assembly - 300 watts Single receiver assembly - 300 watts Quadruple diversity assembly 600 watts
Noise Figure:	6 db (2db parametric is available for additional improvement).
Space Requirements:	One 19" rack houses a complete dual diversity receiver assembly. Two racks house a quadruple diversity terminal. (Maximum floor space 18" x 21" for each rack.)
Sensitivity:	-177 dbw of FSK tone equals 0 db S/N in 130 cps bandwidth.
Combining:	Equal gain.

The basic transmitter (Figure 6) consists of a keyer, a high stability oscillator (1 in 10^8 stability), a 25 watt transmitter and its power supply. This handles short to medium distances. A 500/1000 watt power amplifier is available for use on longer hops.

Description

The basic 25 watt transmitter and the optional PA, together with their power supplies, can be mounted on one side of a 19" relay rack, or in a 69 inch vertical cabinet. (Figure 7).

The basic diversity receiving terminal (Figure 8) consists of two receivers, their combiner for diversity, and a high stability oscillator. A duplexer for the transmitter is necessary if duplex operation is desired. When less system gain is needed, diversity reception need not be used, eliminating 1 receiver, 1 antenna and the combiner.

The basic diversity receiver, together with monitoring functions and power supplies, are again housed in a 69 inch vertical cabinet (Figure 9).

For very long hops the receiver noise figure can be improved from 5 db to 1.5 db by adding parametric front-ends to the receivers. Additional gain can be obtained by using higher order diversity.

For medium length tropospheric paths (100-250 miles) the 250/500 watt power amplifier, along with dual diversity reception, will satisfy most requirements. For longer paths higher power would be necessary. A terminal end of all the necessary RF equipment and antennas less terminal equipment for a 4 to 5 channel medium range one hop TRT system is about $12,000 or $24,000 per hop.

TRT Applications

Advantages

While TRT can be used for shorter distances, its particular attractiveness is for tropospheric distances, for digital communications. It is far more reliable than high frequency radio, since it is operable in the VHF spectrum from 400 to 2000 megacycles, and hence, it is not subject to ionospheric disturbances. It does not require high masts or hills or mountain peaks for its antennas, and provides long hops without repeaters. This provides advantages over microwave or VHF relay, since it is less vulnerable to manmade or natural disaster, and it does not require costly relay points that may be difficult of access, remote from power, and subject to power failure.

Even if we discounted these advantages, it is much less costly than the minimum commercial microwave system for similar distances. It will provide reliable service in areas where it is not practicable to run wire lines, or for services where the terminal location is moved frequently.

TRT provides another tool in the ceaseless endeavor to make more efficient use of our congested and limited spectrum space. It can carry 100 words a minute in a bandwidth of 150 cps, whereas a voice channel, on which it is not possible to sustain this rate for any length of time, requires 2000 to 3000 cps.

Limitations

For point-to-point service, a number of TRT systems could be accommodated in the same amount of spectrum space as that required by a single voice channel, by taking advantage of the reduced bandwidth required and the directivity of the antennas. The limiting factors would be interference due to the transmitter noise envelopes and receiver desensitization. The actual permissible frequency spacing between adjacent TRT systems requires a study of these factors. We are now making such a study.

Thin Route Tropospheric Scatter System provides a new medium for carrying teletype, data, telemetering, canned messages, and even manual telegraphy, over long distances reliably and economically.

Government agencies can use TRT systems for

for law enforcement, toll roads, parks and forestry service, weather reporting, hydrographical information, etc.

At the present, FCC rules and regulations do not provide for use of TRT by licensees in the bands of frequencies administered by the Commission. It appears, however, that many of these users would find significant benefits in the application of TRT. We assume, therefore, that the Commission will want to weigh the desirability of providing some spectrum space for TRT.

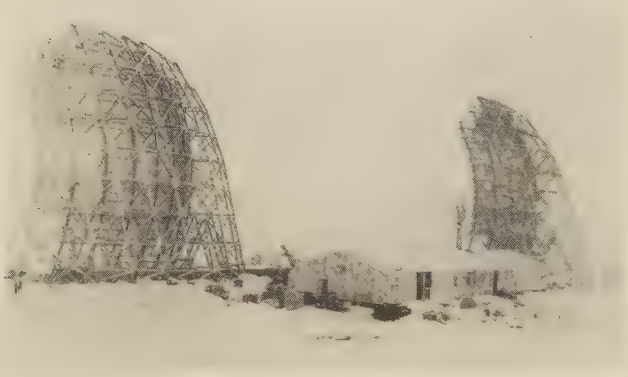

Figure 1 - AN/FRC-47 Antenna

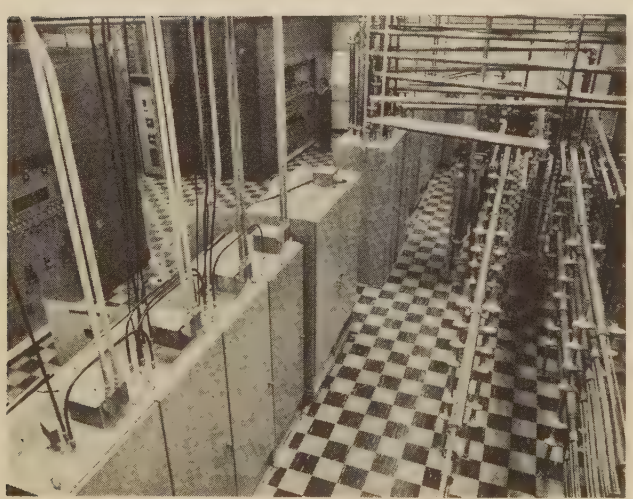

Figure 2 - AN/FRC-47 Station Equipment

Figure 3 - TRT Antenna

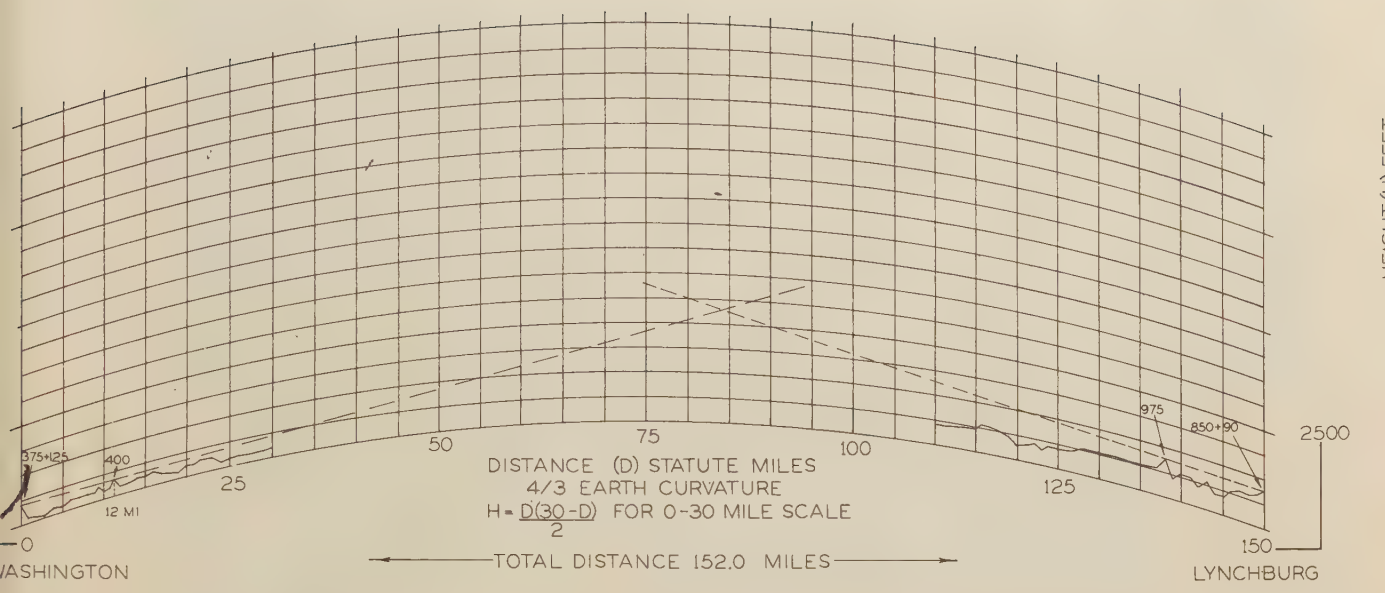

Figure 4 - Profile Map, Washington, D.C. to Lynchburg, Virginia

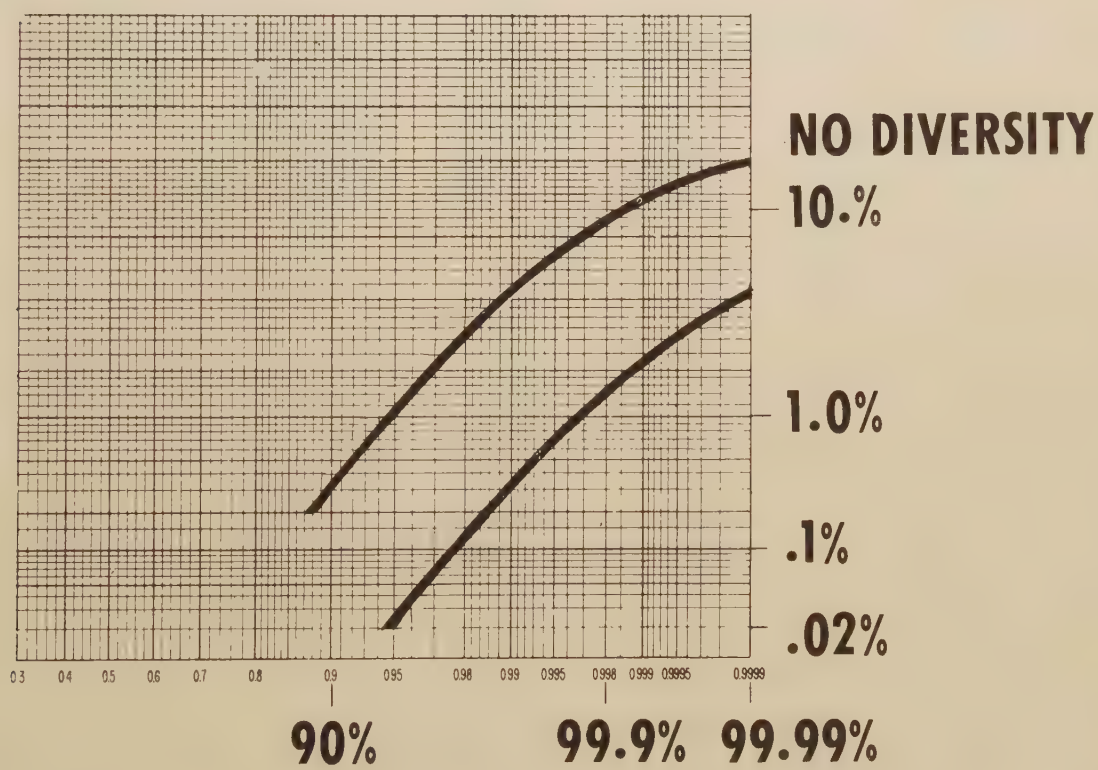

Figure 5 - Character Error Rate

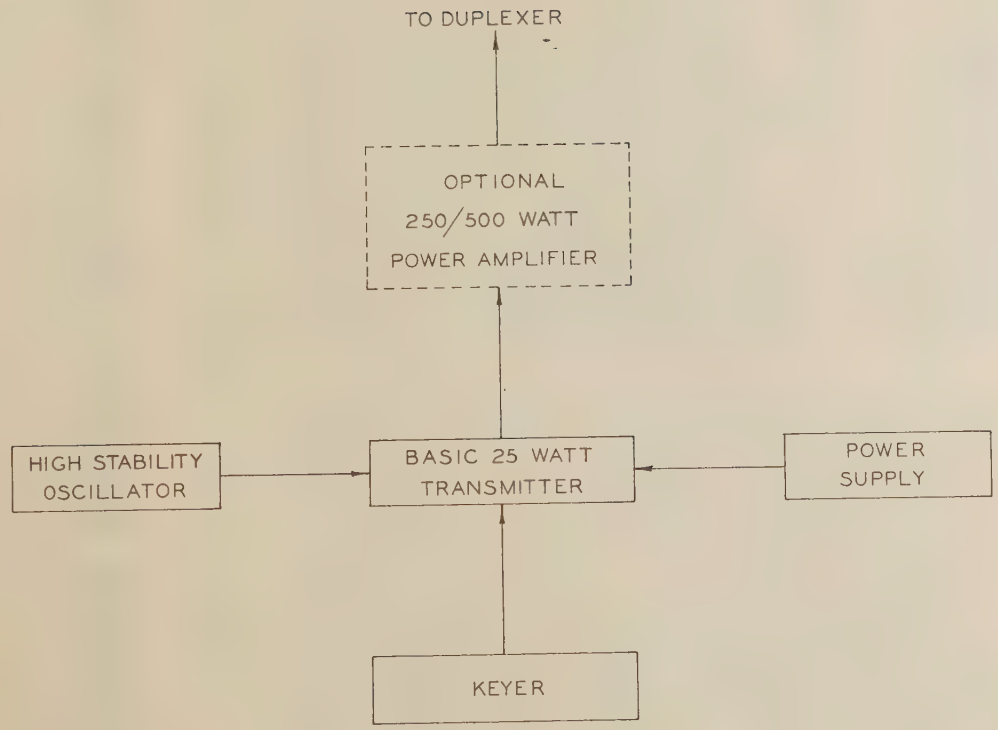

Figure 6 - TRT Transmitter Block Diagram

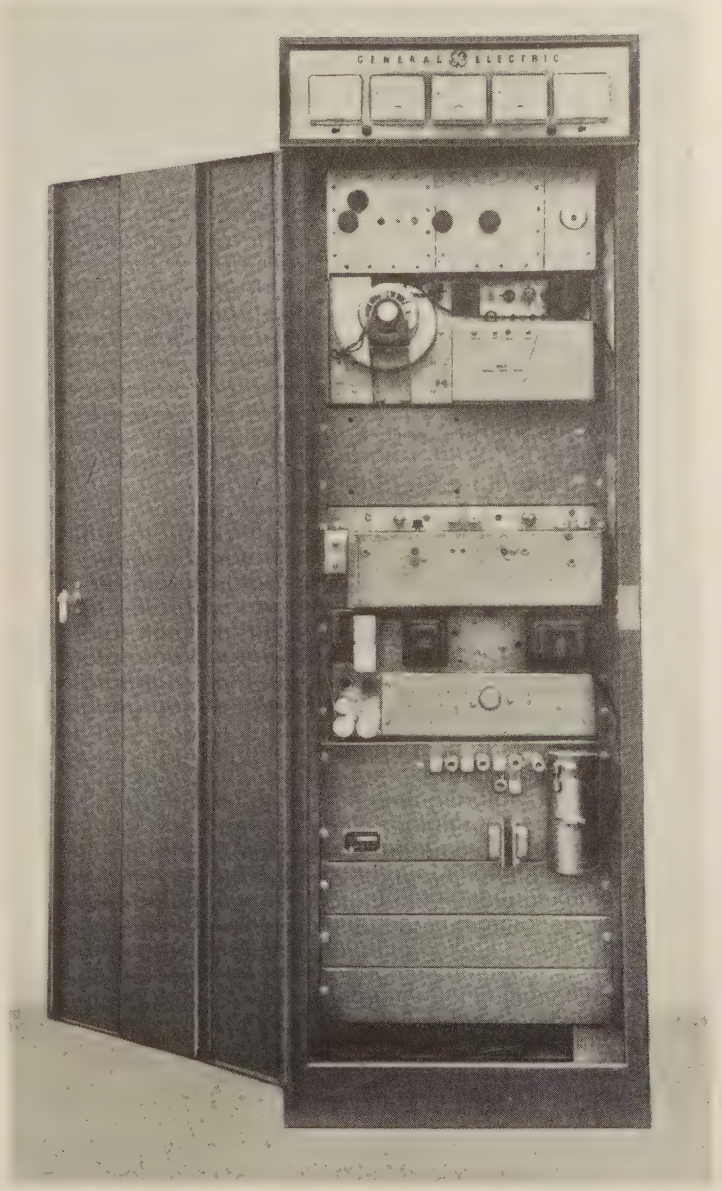

Figure 7 - TRT Transmitter

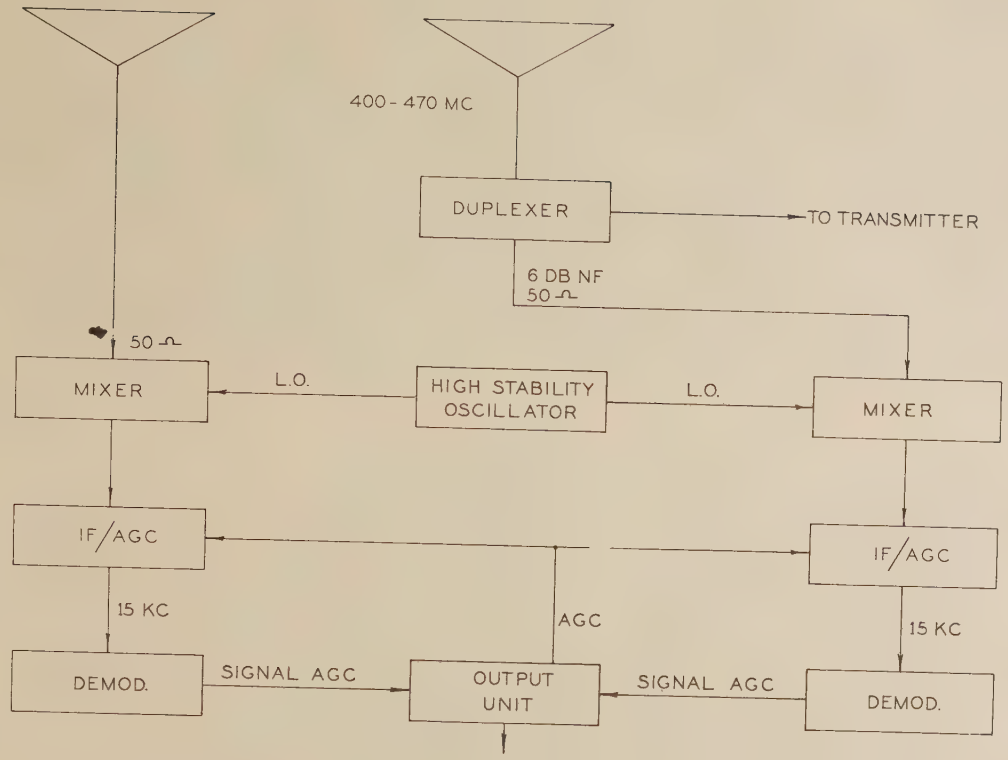

Figure 8 - TRT Dual Diversity Receiving System - Block Diagram

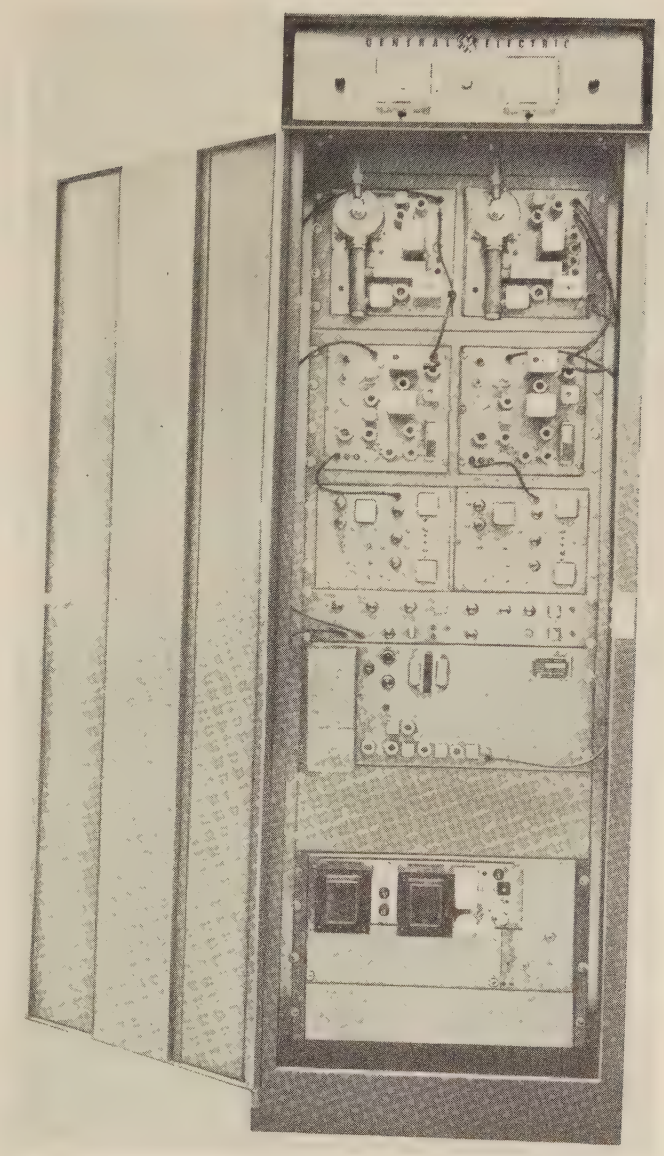

Figure 9 - TRT Dual Diversity Receiving Equipment

A NEW HELICAL GROUND PLANE ANTENNA FOR 30 TO 50 MC.

L. H. Hansen

ANDREW Corporation, P. O. Box 807, Chicago 42, Illinois

ABSTRACT

A unity gain ground plane antenna of greatly reduced size is presented. The ground plane consists of four evenly spaced sloping helices. The fed element is constructed of double helical windings. All the helices are enclosed in Fiberglas tubes.

INTRODUCTION

The primary station antenna for frequencies 30 to 50 MC has been the UNIPOLE antenna, Figure 1. This unity gain antenna usually meets the requirements of 2-way systems in this band, and when directivity is desired, a version of the basic UNIPOLE antenna such as, a cardiod or the bidirectional antenna is used. This general class of ground plane antenna has a quarter wavelength whip or radiator and a ground plane .4λ to .5λ across. For use at 30 to 50 MC, UNIPOLE antenna is a very large and cumbersome unit, the height above the mounting masts is 9 to 11-1/2 feet and the ground plane is 14 to 16 feet across. With elements of this length, the wind loading is severe and the elements themselves must be made relatively large in cross sections to achieve any degree of strength and reliability for the antenna. Aluminum is generally employed to keep the weight as low as possible, but making the unit small and easy to handle is still the most desirable goal.

With the idea of making a smaller unity gain antenna for 30 to 50 MC, an antenna called the HELIPOLE has been developed, Fig. 2 and 3. Efforts were made to shorten all possible dimensions of the UNIPOLE antenna and still maintain its desirable electrical features. The pattern of such an antenna must be omnidirectional and have unity gain, low mast coupling is required, and VSWR should be less than 1.50 with a band width comparable to that of the UNIPOLE antenna.

SHORT RADIATING ELEMENTS

The shortening of radiating elements to something much shorter than a quarter wavelength results in an element having a radiation pattern the same as that of a resonant dipole. The disadvantage of these elements are that they are nonresonant unless some type of loading is used. The devices used for loading often complicates and weakens the structure mechanically and may also contribute considerable losses to the antenna circuit. This points up the need for the designer to make every effort to achieve a self resonant radiating structure so that the losses may be kept at a minimum.

In vehicular applications, short whip antennas are commonly used with a loading device such as small coils. These loading coils are usually short and very little energy is radiated by them; they merely act as tuning coils without affecting any of the other radiation characteristics when connected at the antenna base. These loading coils may be moved up the antenna to some point between the antenna base and top to achieve a modified current distribution. This results in an increase in radiation resistance and therefore an increase in radiation efficiency but with obvious mechanical disadvantages.

Knowing the disadvantages of the short linear radiating element, helical dipoles appear to be a good choice for short radiating elements. The helical dipole may be pictured as a continuously loaded antenna and can be made self resonant. The radiation resistance is higher than that of a linear antenna of the same length, and the pitch and diameter of the helix can be adjusted to give essentially linear polarization.

DESIGN OF GROUND RODS

To make the UNIPOLE antenna smaller and less cumbersome, the largest and most troublesome item, the ground rods must be reduced in size. The 4 ground rods used to make the ground plane were linear resonant elements and were directly replaced by helical resonant elements. Helices wound on 2" diameter Fiberglas tubes were made and trimmed to resonate with the standard UNIPOLE folded dipole radiator. Tests were made of impedance, pattern, and mast coupling of an antenna consisting of a folded dipole with a ground plane of helical elements. The pattern and mast coupling were essentially the same as with the UNIPOLE antenna. The impedance of this antenna

was 50 ohms, with an impedance bandwidth somewhat narrower than the UNIPOLE'S bandwidth.

DESIGN OF RADIATOR ELEMENT

To complete the antenna design, a helical element was designed to replace the folded dipole. This helical element had a twin or bifilar winding to give a higher input impedance. The bifilar radiating element is analogous to the folded dipole, in that both the folded dipole and the bifilar helix operate in the dipole mode and the transmission line mode. The currents in the two conductors are in phase in the radiating mode, and out of phase in the transmission line mode. In the bifilar, the helix pitch and the velocity of the transmission line mode are adjusted so as to give a helical radiating element 1/4 wavelength long, and a transmission line element 1/2 wavelength long and open circuited, Figure 4. This resonant helical radiator shunted with a 1/2 wavelength open circuit element gives a stepped up input impedance similar to that achieved with the folded dipole which is a quarter wave radiating element shunted by a quarter wavelength short circuit element.

TESTS AND PERFORMANCE

The radiation characteristics of this antenna are the same as those of the UNIPOLE, omnidirectional horizontal pattern, and a figure 8 vertical pattern with a beam on the horizon, Figure 5. Mast coupling is as low as that of the UNIPOLE.

The impedance of the antenna is 50 ohms with a VSWR less than 1.50, a Smith Chart plot of a 50 MC unit is shown in Figure 6.

A curve was made for trimming the helices for operation at any frequency for 30 to 50 MC. Several units were tested and found to repeat with excellent correlation.

MECHANICAL ASPECTS

The helices have been constructed of solid wire, flat braid, and flat copper strap, all wound on 2" diameter Fiberglas tubing. Any of these techniques will produce light and strong elements. Each of these are easy to handle and trim so the choice of conductor was based on a combination of material cost and ease of winding on a Fiberglas tube. The tubes have a metal plug in the end which mounts to the pedestal, which is the main section of the antenna. This central portion is an aluminum casting and has the following features: 5 mounting pads to accommodate the helical elements, receptacle for the feed cable, and a mounting clamp which is an integral part of the casting. The mounting clamp will accommodate a standard 1-1/2 in. or 2 inch pipe. The total weight of a 30 MC unit is only 13 pounds, with a height of 6-1/2 feet and a width of 4 feet. The antenna is designed to withstand 30 psf windage with 1/2 inch radial ice load.

CONCLUSIONS

The design of a ground plane antenna of helical elements has been presented. This design is a result of the desire to reduce the weight and size of ground plane antennas at 30 to 50 MC. The use of helical elements and unique construction methods give a unit which is easy to handle, lightweight, and strong. Tests show the HELIPOLE to be equivalent in electrical performance to a UNIPOLE.

ACKNOWLEDGEMENTS

The author wishes to acknowledge that initial conception and development work on this antenna was done by M. W. Scheldorf, formerly of ANDREW Corporation.

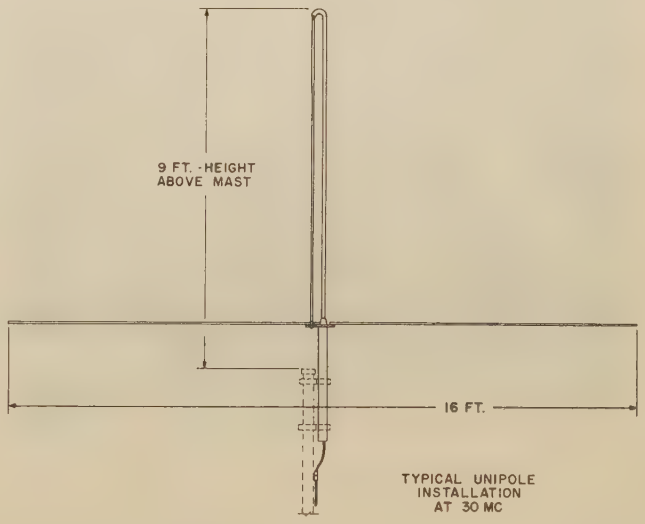

Fig. 1

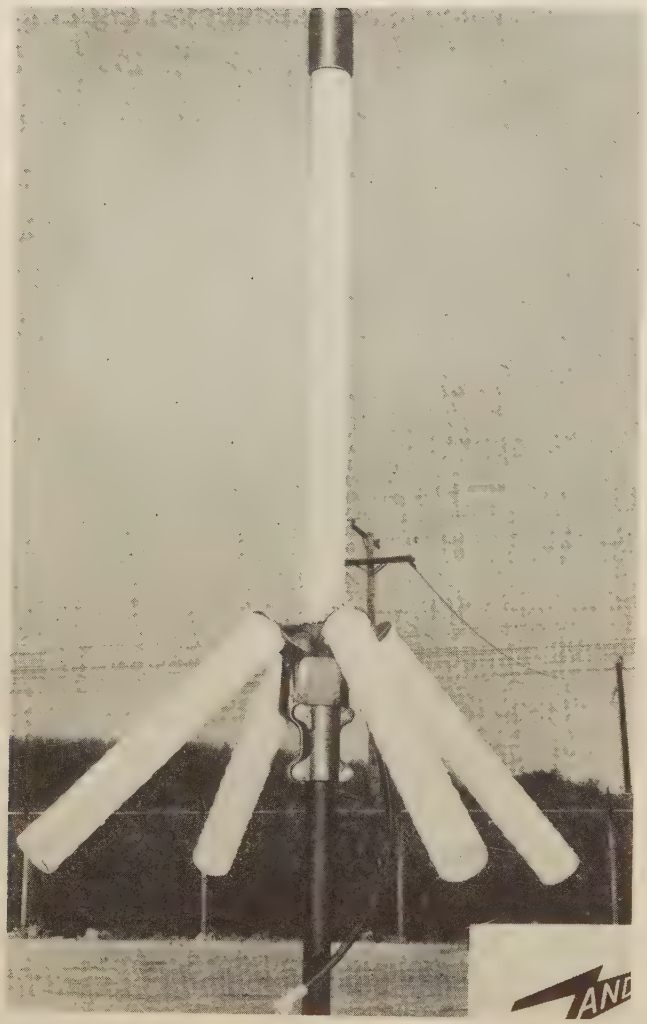

Fig. 2

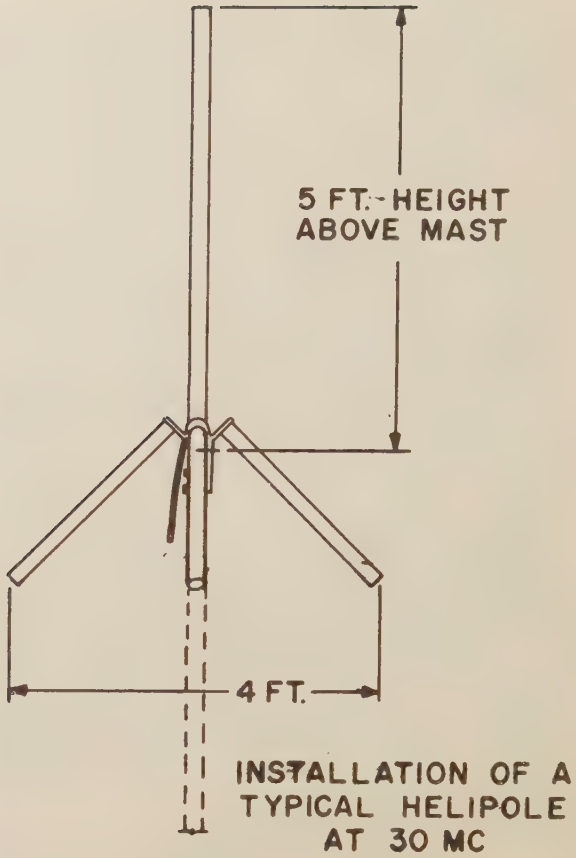

Fig. 3

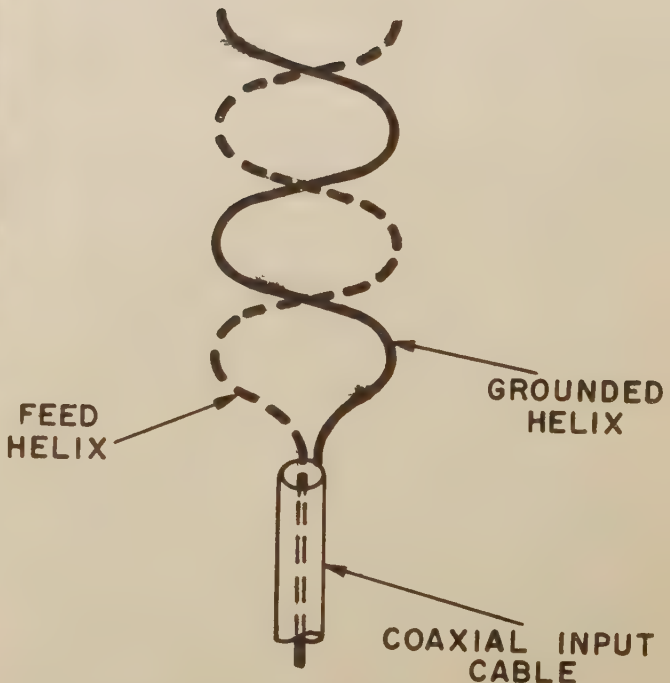

Fig. 4

VERTICAL RADIATION PATTERN
HELIPOLE ANTENNA 50 MC

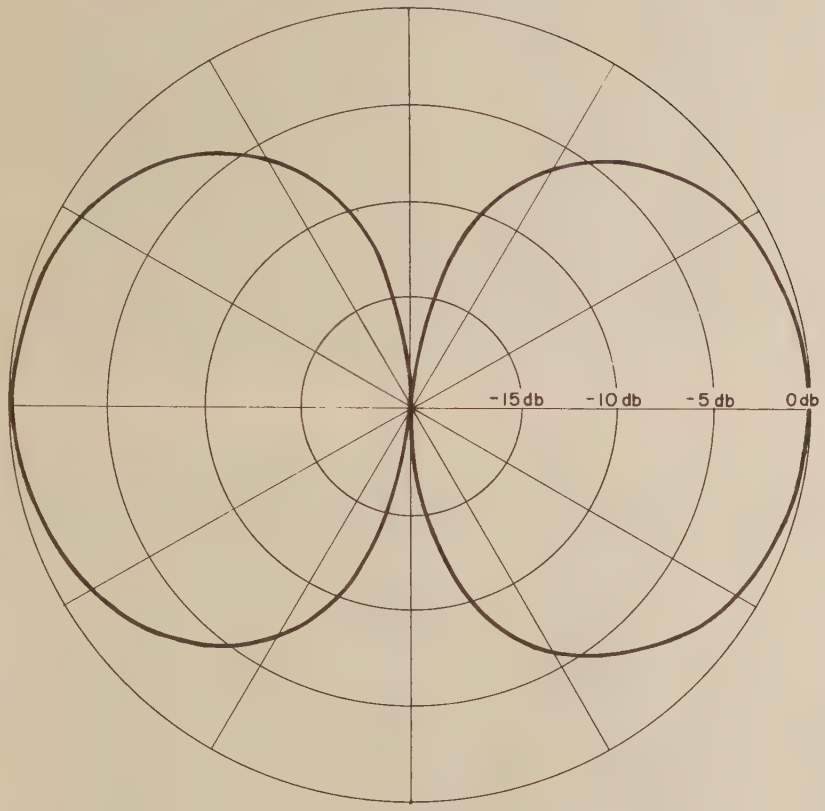

Fig. 5

IMPEDANCE PLOT
HELIPOLE ANTENNA 50 MC

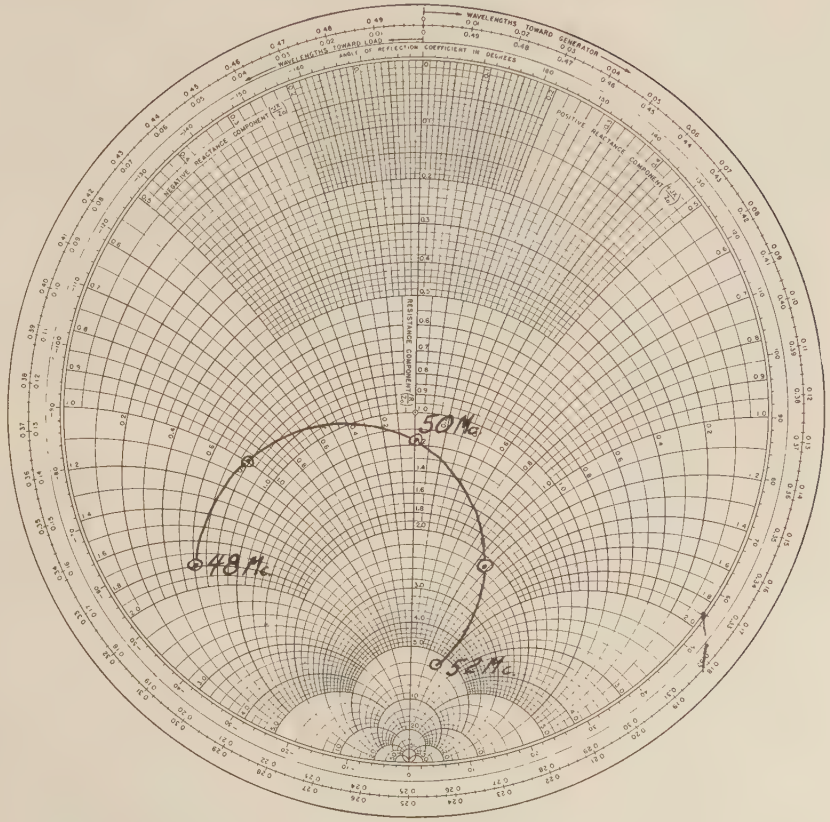

Fig. 6

WIDE-BAND CHANNEL FOR EMERGENCY COMMUNICATION

by

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Summary

A single wideband channel could be assigned to all short range emergency communication systems, resulting in better service and better spectrum utilization. Many independent VHF or UHF mobile users or military nets could use this one channel at random without any form of centralized control or synchronization, and each could transmit different simultaneous emergency messages without significant mutual interference.

In reviewing wideband modulation and addressing (coding) techniques, it is shown that Delta modulation and discrete frequency coding is best suitable for this application.

Introduction

By using a wideband modulation and addressing, or coding, technique, it is now possible for many transmitters in the same geographical area using a common wideband channel to transmit different messages simultaneously without significant mutual interference. This possibility is particularly important to short range, and mobile emergency communication systems operating in VHF and UHF frequency bands. Not only will better service result, but also better spectrum utilization, if all independent emergency systems or military nets would be assigned to single wideband channel, instead of many, individual, narrow band channels. They could use it at random without any synchronization or other form of centralized coordination. The advantages of such an assignment are discussed here first and then the wideband modulation and addressing techniques will be reviewed - the most promising one will be indicated.

Wideband Channel Assignment

At present we divide the available frequency spectrum into many narrow channels, 15 kc to 100 kc wide, and we assign these channels to the individual users of mobile communication or military nets on a more or less exclusive basis. This kind of assignment serves us and will continue to serve us well, but it has several disadvantages. The administration of such an assignment is quite difficult. The users have to be policed to stay in the assigned channel, and if interference develops, channels have to be reassigned. In addition, the equipment built for such an assignment is expensive because it has to be built so that it will operate well within the assigned frequency channel. This includes critical frequency stability, selectivity, and modulation control among other problems. In addition, if for example, a particular channel assigned to our system is jammed intentionally by an enemy as can happen in the military case, or unintentionally by somebody transmitting on the wrong frequency by mistake, we are completely out of luck and out of communication; so the right to use our exclusive channel is worthless to us in this case. In addition, one form of mutual interference, namely intermodulation becomes the most important one as the channels are narrower and more heavily loaded, and it is most difficult to eliminate by equipment design. Perhaps there is a better way to utilize the spectrum. In the case of emergency communication, there is indeed - the assignment of one single, wideband channel to all such systems.

To define what is meant by emergency, all messages can be divided into the two categories of routine and emergency communications. In routine communications, we send messages, one after another. Some messages will be delayed by a few minutes or a few hours depending on channel loading at the time when the messages arrive. In this case, the spectrum utilization will be measured by the number of messages successfully transmitted per megacycle. The assignments of narrow channels are suitable for such systems.

However, in emergency systems, messages cannot be delayed at all. A delay may be very costly, involving loss of lives or property. In case of narrow channel assignments, a separate channel has to be assigned to each emergency system and has to be kept continuously open so that any infrequent emergency message will be transmitted without delay. Channel availability rather than channel loading will be the measure of spectrum utilization in this case, and a single wideband channel should be used for such emergency systems.

If such a wideband channel is assigned, Figure 1 shows how many independent systems or nets dispersed in a given geographical area can use this one channel. Each dot on this figure represents a transmitter which can be in communication with other dots of the same type. Each system has immediate access to this common channel at random and by using appropriate wideband and addressing techniques, many simultaneous conversations could take place over this single channel with a minimum amount of interference. This arrangement is called RADAS[1] which stands for, Random Access Discrete Address System. The problem will be to select the best wideband modulation and addressing technique so that the maximum number of simultaneous talkers could be accommodated in such systems with minimum interference.

Wideband Techniques

Wideband techniques can be divided into two general kinds. One will be called a CW technique. In this technique, the transmitter is continuously transmitting a signal, and modulation is so arranged that the transmitter power is distributed over a very wide band and at a low power density per kilocycle (frequently below the noise density level). Such systems are sometimes called Quasi Random Signal or Matched Filters techniques, depending on implementation. The simplified principle of this type of transmission is shown in Figure 2. Briefly, instead of transmitting a single AM or FM modulated carrier a spectrum is transmitted consisting of several hundred or thousand of such weak carriers; only 10 of them are shown for simplicity in this figure. These individual carriers can be coded, for example, by inverting their phase as shown here. The receiver to which the transmission is destined knows how to decode these carriers, which means how to add them in phase as voltages while all other receivers will add them as power. It follows that the greater the number of individual carriers or the more bits we transmit for each information bit and the wider is the channel expansion we use, the better distinction we have between properly coded messages addressed to us, and wrongly coded messages, addressed to somebody else. For example, if we expand the modulation bandwidth a thousand times and use 10 megacycles bandwidth instead of the 10 kilocycles required for a single carrier carrying voice modulation, we will get a 30 db distinction between the desired and undesired address or code, provided that the two signals arrive at the receiver input with the same strength. But what will happen if the undesired transmission is 30 db stronger than the desired one? Unfortunately, it will completely obscure the desired transmission. These systems have, therefore, a limited dynamic range. Incidently, the simplest case of CW technique is the double sideband transmission (DSB)[2] in which the dynamic range and the code recognition is limited to 3 db.

In mobile operation where many independent transmitters are present in the same geographical area, a wide dynamic range is necessary. Therefore the CW systems will not be suitable for this application as shown in Figure 3. Short range, ground based mobile systems rely on propagation of the ground wave, which is attenuated theoretically 12 db per octave but in practice, according to many field measurements, 15 db per octave of distance. This means that as we double the distance from the transmitter, the signal strength will decrease by 15 db. If a CW system were used with 30 db address recognition (which means modulation band was expanded at least 1000 times), and then if a desired transmitter is four times further than some other undesired transmitter as shown in this figure, the signal from the undesired transmitter will completely obscure the transmission. One can see that this system will not permit the operation of the receiver in the vicinity of the undesired transmitter - frequently the situation encountered in mobile systems.

Wideband Time Sharing Technique

The other wideband technique which will be useable in this application is time sharing in which each transmitter radiates groups of short pulses. Each group carrys voice modulation and the address in some form. In this case, as shown in Figure 4, the pulses are not synchronized and infrequently the different transmissions may coincide and the pulses may fall one on top of the other. This can cause some small amount of interference which can be minimized by proper selection of the address and the modulation scheme. In general, there are two possible approaches. One is to transmit at a low duty cycle - which means short and infrequent pulses, and the other is to use redundant transmission - which means to transmit a group of related pulses instead of a single pulse. This redundancy will require additional transmitter power which will not contribute to the extension of the range of communication. The pulses in the group can be transmitted as bursts of different radio frequencies, or, they can be spaced in time. This will not only provide the address, but will also decrease the interference since destruction of one or two pulses in the group by an interfering transmitter will not be detrimental as long as at least one of the redundant pulses in the group is transmitted properly. In such a time sharing system the receiver may be equipped with a time gate which will open only for the short period of time when the desired pulse is expected. The receiver will be muted during the rest of the time. This way, no matter how strong the interfering pulse is it will not be received at all unless it falls on top of the desired pulse. Therefore, there is no dynamic range limitation in this system. The receiver can operate close to other powerful transmitters-even a duplex operation with a single antenna is possible in this system.

Delta Modulation

In trying to select the optimum modulation and address scheme it was observed that Delta modulation is particularly advantageous for this application. Delta modulation[3] is not new and Figure 5 gives a simple explanation of this modulation. The voice curve is sampled perhaps 20,000 times a second and is reproduced approximately by using small fixed segments of positive or negative slope as shown in the figure. Each time the reproduced voice curve falls below the voice curve, a pulse is transmitted signifying the positive slope, and when the reproduced curve exceeds the voice curve at the time of the sampling, the pulse is omitted. As can be seen, the voice curve can be reasonably reproduced by the transmission of a train of pulses, or no pulses, at a uniform rate. The low pass filter at the receiver will remove the high frequency ripple leaving a relatively undistorted voice curve. Delta modulation is the simplest analog-to-digital conversion of voice, and thus has all the well known advantages of digital communication.

The address scheme can be provided by transmitting each Delta modulation pulse not as a single RF burst but as a series of RF bursts on different, discrete, frequencies. Three such bursts are shown in Figure 5. These frequencies all lie within the wideband channel, which means that the channel is sub-divided to provide several frequencies from which the addresses are selected. Experiments proved that addresses using discrete frequencies rather than spacing pulses in time, provided better address recognition and consumed less bandwidth per talker.

Advantages of Delta Modulation

Delta Modulation has many advantages for this application. The more important ones will be mentioned here.

It has a low pulse rate and low duty cycle as compared with PCM or other digital modulations. For example, only 10,000 pulses per second are transmitted in average, when 20,000 voice samples are taken per second. This will definitely minimize the interference. In addition, the pulses are transmitted at a fixed rate, so the receiver knows when to expect the pulse and can be equipped with time gates as shown in Figure 6. The receiver is open only during the short period of the time gate, and is muted the rest of the time, thus rejecting all the interference most of the time, no matter how strong the interference may be.

Another advantage of Delta modulation for this application is that if the interfering pulse falls upon the transmitted pulse, the receiver will recognize that the pulse was transmitted, even if the interfering pulse was much stronger than the desired pulse. Therefore, there will be no evidence of the interference in the voice output of the receiver. This means that the interfering pulses can do damage only half of the time when no desired pulse was transmitted. Even in this case there must be a sufficient amount of interfering pulses so that at all three address frequencies as shown in this figure, the false pulses were received in the right time slots. Only then will the receiver coincidence circuitry recognize that a pulse was transmitted, when in fact the desired pulse was not actually transmitted. This means that a lot of interfering pulses can be transmitted over the same channel (as a simple probability calculation shows), before there is a serious chance of interference.

Finally, even if a false pulse transmission is recognized by the receiver, it will do a very small amount of damage to the voice output curve. Each falsely received pulse will simply replace one segment of the negative slope by segment of the positive slope. As far as the output curve is concerned, this corresponds to an error of two quantizing levels, which is a rather small effect to the listener. This short discussion shows the reasons why the described modulation and addressing method is the most suitable for this application.

Equipment Configuration

For those interested in hardware, Figure 7 shows an example of a block diagram of a Delta modulation transmitter, to prove how simply this system can be implemented. The Delta modulator itself consists of a feedback loop in which the pulses are integrated and amplified to reproduce the voice curve. This reproduced voice curve is subtracted from the original voice curve in the comparator. The positive or negative voltage difference from the comparator, closes or opens the gate. The 20 kc clock, which is the assumed voice sampling rate, generates short pulses which can either pass or will be stopped by this gate, depending on comparator output. Thus, a Delta modulation train is formed out of clock pulses. To provide address at the transmitter, three separate oscillators are used and are connected to the common RF amplifier through three separate gates. Delta modulation pulses are applied to a three step shifter which could be in the form of three mono-stable flip-flops. When the Delta pulse is received by the first flip-flop, it opens the first gate for a definite period of time permitting the first frequency to be applied to the final RF amplifier. Then, it flops back passing the pulse to the next stage which opens the second gate and finally to the last stage which opens the third gate. In this way, three short consecutive bursts of three different frequencies are applied to the final RF amplifier and are transmitted for each Delta modulation pulse. This short description of the transmitter was shown here only to prove how simply this system can be implemented as compared with other broad band modulation schemes.

System Performance

Experimental results and calculations show that this type of a system will accommodate perhaps five simultaneous talkers per megacycle, with a conservative interference level of 30 db. To give some meaning to this and to show what can be expected from this system as far as spectrum utilization is concerned, let's assume that we have one megacycle of spectrum to be utilized for emergency systems. We can divide it into twenty 50 kc channels (as in current military practice) thus accommodating 20 emergency systems in a given geographical area. Let's further assume that these emergency systems transmit over the assigned channels 10% of the time, which is a rather high channel utilization for emergency systems. The other possibility is to take this one megacycle spectrum and assign it as a single, common, channel to all these independent emergency systems. In this case with 20 emergency systems having 10% duty cycle, we will have only two simultaneous talkers in average, yet our system capability is 5 talkers. Therefore we can assign 50 emergency systems in the same bandwidth instead of 20, which means a factor of $2\frac{1}{2}$ in spectrum utilization. But this is not the whole story, these 50 systems will have a much better chance to get through regardless of jamming or interference. The wideband system of this type has soft over-

loading characteristics. By this it is meant that if the number of talkers will exceed 5, all that will happen in this case is that the noise caused by interference will be increased from 30 db to perhaps, 20 db below voice level, but only in those receivers which happen to be listening to transmitters at the maximum range at the time. Then if the number of talkers increases further, the communication range of the system will be somewhat limited by interference and may decrease, for example, from 20 miles to 14 miles if the number of talkers per megacycle is quadrupled. We should remember that in this system we have a much better chance of getting through even if the overloaded system produces increased background noise. In the narrow-band channel system however, we may be completely out of communication if our channel is interfered with. Not only we will obtain a better spectrum utilization, but also a better service for emergency systems, if we utilize this concept of a single wideband channel.

In conclusion, it was shown that wideband channel assignment and wideband technique is a very promising solution, particularly for short range emergency systems.

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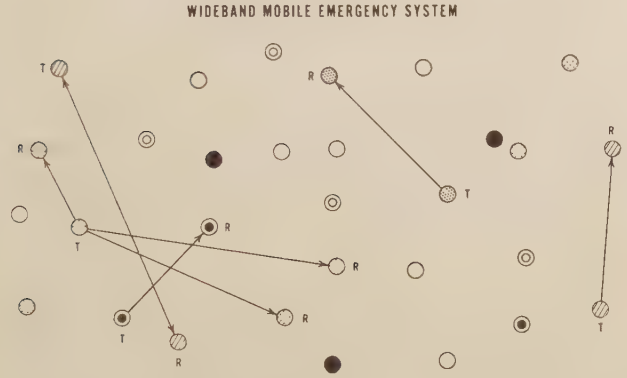

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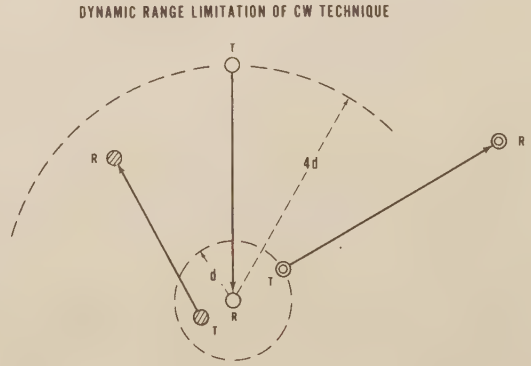

Fig. 3.

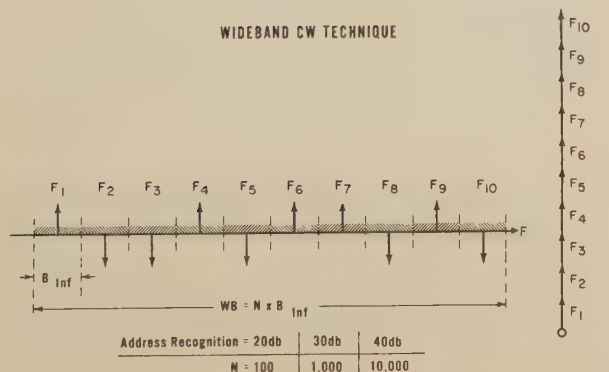

Fig. 2.

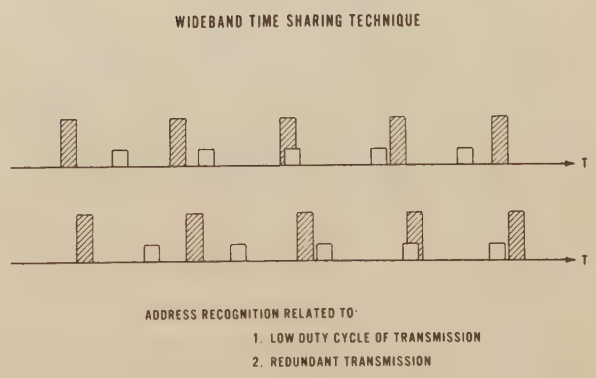

Fig. 4.

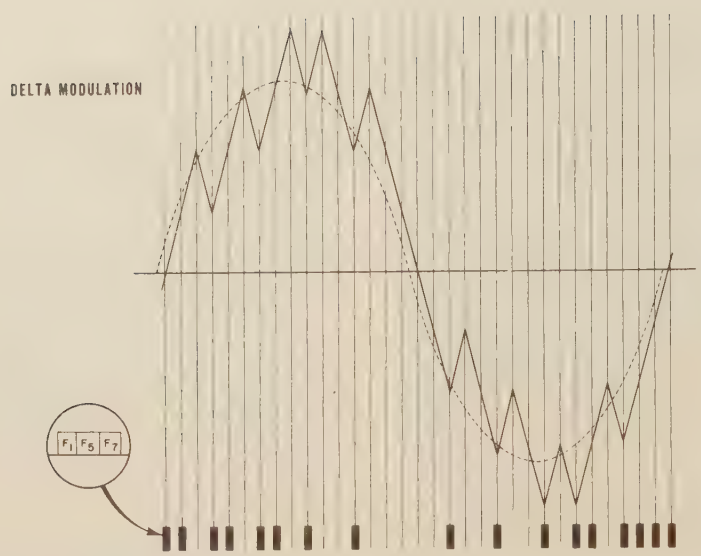

Fig. 5.

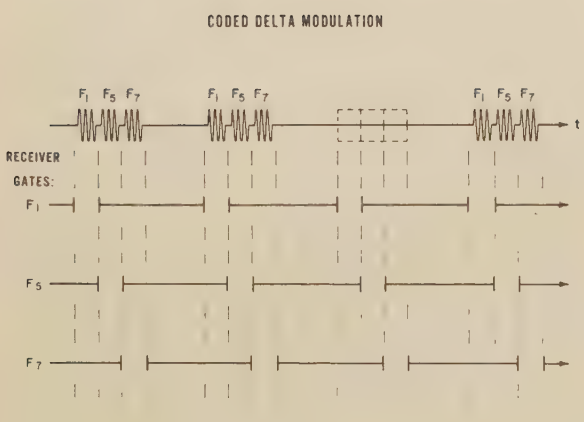

Fig. 6.

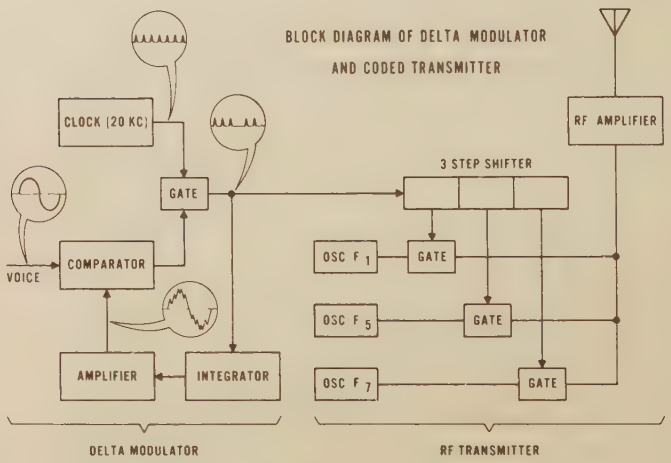

Fig. 7.

TONE SIGNALLING INCREASES MOBILE RADIO EFFICIENCY

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Much of the pioneering work in the use of two way radio was done by the nation's gas, electric and water utilities. The ever increasing requirements for energy in the form of electric power and gas and the enormously expanding need for water make it necessary for these utilities to utilize every new technique or device that will contribute to improved efficiency and continuity of service. Mobile radio has, over the years, proved to be an extremely versatile and useful tool and, in fact, almost every utility now operates an extensive radio system.

Other industries have also discovered the usefulness of radio and the present demand for spectrum space far exceeds the available supply. The number of channels derived from a given amount of spectrum has been increased by reduction of channel width and improvements in equipment. Orderly assignment of channels to realize the maximum number of licensees on each frequency has helped to meet the need, but the supply still lags behind the requests for channel assignments.

The Federal Communications Commission has made a heroic effort to furnish everyone who needs radio with a suitable operating frequency and, with the cooperation of the affected industries and agencies, has succeeded in large measure. It is obvious, though, that the problem will become increasingly difficult as new uses for radio are found and since, in the present state of the art, little or no new spectrum space can be found for this purpose.

Many utility radio systems are now saturated with voice communications and no additional channels are available to provide for system growth. In this connection, electric and gas systems are currently doubling the number of customers served every ten years.

The National Committee for Utilities Radio (NCUR) has long been aware of this problem and has been studying possible solutions. NCUR represents the electric, gas, water and steam utilities in matters pertaining to radio and is largely responsible for the efficient manner in which radio channels assigned to the Power Radio Service are now being used.

One of the most interesting possibilities for greater utilization of radio frequencies is the substitution of coded audio tones for voice. It is this development with which this paper is principally concerned.

Several years ago, at the request of NCUR and a number of rural electric cooperatives, the FCC amended the rules governing the Power Radio Service to allow the use of automatically operated, unattended fixed transmitters carrying tone modulation for the specific purpose of reporting failures on electric power systems. A number of these devices were installed and are operating today providing an invaluable service to the utilities and their customers. Since these units operate on the same frequency as the licensees mobile radio system, they require no additional radio channels. It should be noted that all such devices are limited as to length of transmission, band width, repetition rate and other particulars to conform to the requirements for voice communications. They are licensed on a secondary basis only and no mobile service frequencies are licensed solely for signalling purposes.

The FCC, after careful consideration of a petition by NCUR for rule changes which would allow expanded usage of tones for signalling and control purposes and comments by other interested parties, released a report and order on January 9, 1961, (Docket No. 13812) which liberalized the rules governing the Power Radio Service to permit the use of tone transmissions by base or mobile radio stations for a number of operating purposes. This ruling also made the new technique available to gas, water and steam companies as well as the electric utilities who had been given this service in an earlier proceeding.

Briefly, the new rules may be summarized as follows:

Tone or impulse signalling may be employed on mobile radio service frequencies above 25 mc/s in the Power Radio Service on a secondary basis to voice communications subject to the condition that harmful interference is not caused to the primary operations of any other licensee on the particular frequency. All such secondary use is subject to the following limitations:

(1) The only purposes for which such secondary signalling may be used are:

(i) Automatic indication of failure of equipment or service in the production, transmission or distribution facilities of the licensee.

(ii) Automatic indication of an abnormal condition in the production, transmission or distribu-

tion facilities of the licensee, which if not promptly corrected would result in failure of the equipment affected.

(iii) Manually supervised transmissions as may be necessary to restore lost service, place standby equipment in operation, or to correct any abnormal condition, which otherwise would result in an immediate failure in the production transmission or distribution facilities of the licensee.

(2) Any one alarm, warning or corrective requirement utilizing secondary tone or impulse signalling shall be limited to not more than five transmissions, not to exceed six seconds each, and no two transmissions shall commence in the same sixty-second period.

(3) The bandwidth utilized for secondary tone or impulse signalling shall not exceed that authorized to the licensee for voice emission on the frequency concerned.

(4) Frequency loading resulting from the use of secondary tone or impulse signalling will not be considered in whole or in part as a justification for authorizing additional frequencies in the licensee's mobile service system.

(5) A mobile service frequency may not be used exclusively for secondary tone or impulse signalling.

It should be noted that many functions described above are now being performed over leased wire lines, microwave circuits, wire carrier circuits and fixed radio installations and this will continue to be the case. It would be impractical and unrealistic to suggest that any such circuits would be supplanted by tone operated devices on mobile service frequencies. There are, however, many cases where conventional circuits are either unavailable or impractical.

For example, warning devices are often needed at a location where wire circuits are unavailable or unreliable and the cost of construction would far exceed the benefits to be derived. In the gas industry, with which I am most familiar, unattended transmitters which will automatically originate a coded tone signifying a failure and its location can profitably be employed on pipelines crossing rivers in remote areas. Prompt receipt of such information will allow steps to be taken which may present loss of service to many consumers. Frequently this will be the only practical way to obtain the necessary information as quickly as it is needed.

Of course, it is not possible to foresee all of the possible applications of the technique of signalling and controlling by use of tones, but the following may convey some idea of the presently contemplated uses.

Electric Utilities

Control of Off-Peak Loads

To turn on and off certain off-peak loads from a central location.

This function is now accomplished with time clocks, but these clocks get out-of-step during power shut downs and, of course, time clocks do not recognize holidays and other irregular conditions. Also, when a power outage occurs during a heavily-loaded period of the day, it may be necessary for an operator to break up the load before it can be picked up again which is time consuming and of considerable inconvenience to the general public.

To perform this function by coded tones on mobile frequencies will permit substantial economies for both the customer and the company; and, it will permit dumping non-essential loads during certain emergency periods of system disturbance and will avoid outages to essential loads.

Wire circuits for this purpose may be impractical, very uneconomical, and unreliable because of the remote and scattered locations at which this function must be performed.

Air time for this additional function will be very small (a few minutes per day).

Substation Alarm Indications

To transmit several types of information from a large number of unattended substations to central attended location.

Coded tones on mobile frequencies will be used to transmit information such as high temperature of equipment, switch operations, grounds and other abnormal conditions in the station.

Supervision and Control of Pole-Top Switches

To permit operation of a large number of pole-top switches from a central control point and to check position of any switch.

It is impractical and uneconomical to provide wire or carrier circuits for this operation; because although

circuits must be available on a 24-hour-a-day basis, the actual operating time is only a few seconds a week. Thus, use of coded tones on mobile frequencies can perform this function most economically and with a minimum use of air time.

Control of Capacitor Banks

To control a large number of capacitor banks from a central location.

This operation is now controlled by time clocks, but this does not provide for unusual conditions such as abnormal load distribution, line outages, holidays and major system troubles. The conduct of this operation by coded tones will allow better control of power factor correction resulting in better voltage regulation for the customer.

Radio Phase Identification

To permit identification of the phases of power line conductors.

It appears possible that this may be done by comparing the phase of the power line conductors with a phase identification tone, lasting only a few seconds, transmitted by a base station.

Gas Utilities

Alarm Signalling

a. Indication of abnormal pressure on distribution or transmission system.

b. Indication of excessive rate of gas flow.

c. Indication of pressure regulator failure.

d. Indication of escaping gas at critical points, such as compressor stations, regulator stations, gas production plants, etc.

e. Indication of compressor failure at unattended stations.

f. Indication that an automatic safety shut-off device has operated.

g. Indication that a relief valve has operated.

All of the above information, if received quickly and reliably, is extremely important. For example, prompt attention to a sudden drop in pressure may avoid loss of service for thousands of customers. While many of the above functions are now being handled on other types of circuits, the new rules make possible practical "back up" circuits which may be employed in event of failure of the normal facility.

Control Functions

a. Closing or opening of line valves from base or mobile stations.

b. Resetting pressure regulators.

c. Starting and/or stopping of compressor stations.

d. Valving in or closing off auxiliary gas supplies from storage such as repressured wells or gas holders.

e. Reclosing relief valves at large stations after overpressure condition causing relief valve to operate has been corrected. (Some relief valves must be manually reset after each operation.)

f. Reopening automatic safety shut-off valves after correction of condition that caused them to close.

Water Company Uses

1. For use in low water impoundment facilities in connection with reservoir level control, particularly during periods of excess rainfall, at which times it is necessary to release controlled amounts of water, both from the standpoint of protection of the facilities, as well as property downstream and during periods of drought, when the conservation of such storage is essential.

2. For the control of filter water storage reservoirs and elevated tanks.

3. For the transmission of pressure and flow information in connection with the operation of water booster stations.

4. For chlorination station monitoring. This is very important from the standpoint of protection of the public water supply.

5. For the remote control of major water distribution line valves in connection with failure in such facilities.

Steam Utilities

There will be little application for tone signalling by the steam utilities; however, there may be an occasional application for reporting of trouble at locations where such trouble might endanger the public.

In order to utilize fully this new method of using the mobile radio frequencies, it will be necessary to develop extremely reliable encoding and decoding apparatus. It should be obvious from the uses described above that inadvertent operation or malfunctions cannot be tolerated. The degree of equipment reliability that will be required far exceeds that now found acceptable for miscellaneous signalling purposes; such as, selective calling systems. There can be no doubt that such equipment can be designed and can be marketed at a price that will make it attractive to the utilities of the nation. Probably some of the techniques employed for communication with satellites will find a more prosaic application in this instance.

The form of "read out" will range from a simple alarm lamp to automatic typewriters which will print all necessary data, such as time of occurrence, location and nature of fault.

In the control field, the utmost in reliability is mandatory. Such reliability can likely be obtained by the use of a number of discrete tones, the number, sequence and duration of which must be correct to initiate an operation. Some equipment now on the market will meet a portion or possibly all of these requirements.

Ultra-reliable radio transmitters and receivers which require a minimum amount of primary power must be developed. The present state of the art should permit the development of transistorized units which could use thermopiles as their power source. Obviously such devices would be extremely useful in the gas industry and would probably find acceptance by the electric utilities since they could operate from a readily available fuel source, such as bottled gas. Units of this type will be completely free of requirements for commercial power, telephone lines or other limiting factors and will be most useful in remote, unsettled areas.

Within the framework of the rules released on January 9, 1961, there is considerable room for experimentation and expansion of the secondary use of radio frequencies now being employed for mobile radio systems. It seems certain that this will result in more efficient utilization of both spectrum space and equipment and, therefore, greater certainty of the continued high standard of utility services to which we, as a nation, have rightfully become accustomed.

Looking far ahead, the time may come when we can no longer afford the luxury of voice contact for routine purposes since the same information may be transmitted much more quickly and accurately by devices which have their own "voice" in the form of tone bursts of very short duration. Certainly adoption of the devices and techniques discussed in this paper is a step in that direction.

A NEW APPROACH TO TRANSISTORIZATION OF MOBILE RADIOTELEPHONE EQUIPMENT

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SUMMARY

An equipment design is described in which transistors are employed in both receiver and transmitter to reduce power drain and increase reliability. The following design objectives are believed successfully met:

Low power drain in receive condition.

Tuning adjustments minimized by use of lumped ferrite filters for both first and second I.F. selectivity of receiver.

All components easily and quickly accessible for maintenance.

Up to eleven r.f. channels available within a one Mc/s band for both receiver and transmitter. Thus particularly adaptable to Maritime VHF.

Manufacturing cost of same order as vacuum tube designs of similar r.f. power output.

A detailed description is given of a compact unit suitable for either underdash or trunk mounting in vehicular installations.

The object of this paper is to describe the design of a compact transistorized mobile radiotelephone suitable for vehicular or multichannel marine applications.

The use of transistors in such a design has three obvious advantages:

(1) A reduction of power drain, especially in the receive condition.

(2) A reduction in size and weight of the equipment.

(3) A marked improvement in reliability and extension of the mean time between failures. This last advantage is, however, very dependent on the operation of the transistors conservatively within their ratings, especially within their thermal ratings.

Mobile equipment is often operated in a land vehicle or marine vessel for long periods of time with the engine shut off, or in vehicles or boats having a very limited power capability in their electrical systems. Thus, minimum power drain is a very definite operational requirement.

From the reliability aspect there is considerable evidence that transistors have greater reliability than vacuum tubes, when both devices are operated within their ratings. Moreover, the large voltage fluctuations characteristics of mobile electrical systems affect the reliability of vacuum tubes more than transistors.

The requirement of the design to be described is such that the advantages of transistor usage are not attained at the expense of certain desirable attributes of comparable present-day vacuum tube designs. The specific design objectives that are to be met under this heading can be summarized as follows:

(1) Manufacturing cost of the transistorized radiotelephone must be of the same order as the cost of a comparable equipment using vacuum tubes.

(2) Ease of maintenance must be of the same standard as that of vacuum tube units. This calls for use of non-selected components, plug-in transistors and use of printed wiring only if component replacement is not compromised. Modular construction is not used where it materially increases the difficulty of circuit checking or component replacement.

(3) In all of the important operating parameters covered by EIA, FCC and Canadian Department of Transport specifications it was considered necessary that the transistor units have at least as high a standard of performance as the corresponding vacuum tube units. It seemed obvious that for many users the advantages of transistorization could not offset the disadvantages of deteriorated performance.

The techniques of miniaturization, large-scale use of printed circuitry and the employment

of modular construction may be justified in portable equipment, where size and weight are a primary consideration. This is not necessarily true in vehicular or marine equipment. Some of the disadvantages of these techniques are:

(1) An increase in the manufacturing cost.

(2) A great increase in the difficulty of maintenance. This is particularly true if components cannot be replaced without removing a module and if the equipment cannot be operated with the module remote from its normal position in the equipment. Printed circuits have the very real problem that the replacement of components on a printed board having high component density is not only a time consuming process, but carries a high liability of damage to neighbouring components or to the printed board itself.

(3) A decrease in reliability will result from miniature modular construction unless very great care and skill is exercised during maintenance. Miniaturized construction will also increase the thermal design problem, which is a particularly important consideration when transistors are used.

Most mobile radiotelephone equipments employ a multi-unit construction consisting of a control head and loudspeaker mounted in the vicinity of the operator. The transmitter, receiver, and power supply unit is mounted remotely from the operator, say in the trunk of a passenger vehicle. Appropriate control cables are used for electrical connection between the two units. An alternative design would mount the entire apparatus in the operator's vicinity under the dash of a vehicle and the interconnecting cables would be eliminated.

There are a number of important advantages to the single unit underdash type of construction. These can be summarized as follows:

(1) Higher reliability due to lower maximum temperatures in the vicinity of the operator as compared to the trunk of a car or similar location. The elimination of plug and socketry associated with underdash construction is also a reliability feature.

(2) Simpler maintenance is possible due to the use of a single unit in an accessible location, to the elimination of control cables and similar accessories in setting up the equipment for operation on the service bench.

(3) A lower manufacturing cost due to a simpler construction and less material and labor requirements.

(4) A simpler and quicker installation procedure permits rapid movement of units between vehicles often permitting a single unit to perform a variety of functions in a communications system.

(5) Improved performance is attainable in many instances due to the elimination of interference resulting from pickup of extraneous signals by control cable wiring. Hum and noise-modulation problems on the transmitter carrier is a typical example.

These advantages of single-unit construction have long been apparent to designers of mobile equipment. However, the limited space available under the dash of modern vehicles has made such equipment impractical in many cases when vacuum tube designs were used. A partial solution to this problem has been the separation of the power supply from the rest of the equipment with both units being mounted in the general vicinity of the operator. However, in the transistorized design to be described the advantages of a true single unit design can be made available for almost all installations at power output levels of up to sixty watts.

Thermal design considerations largely govern the reliability of both vacuum tube and transistor equipment. In the case of vacuum tube equipment, tube life is increasingly reduced when envelope or pin seal temperatures exceed those recommended by the manufacturer. In the case of transistors, exceeding the maximum rated junction temperature results in a permanent change, or complete breakdown of transistor action. Of course, transistor ratings carry an engineering margin of safety which, however, is much smaller than in the case of the thermal ratings of vacuum tubes, and the breakdown occurs in a much more abrupt fashion.

The thermal design of a mobile radiotelephone has two major aspects. These are:

(1) Provision for dissipation of heat to the external environment by the specific heat-producing elements in the equipment.

(2) Reduction of the temperature of the external environment to a minimum value so as to permit the most effective heat dissipation by creating a maximum temperature differential between the unit and its environment.

Heat dissipation by radiation is limited by the emissivity and surface area of the external surfaces of the unit. Obviously as the

equipment becomes smaller the temperature rise will increase unless the amount of heat to be dissipated is proportionately decreased. A practical size of a single unit under-dash mount equipment might be 4" x 11" x 12" or approximately 400 square inches of radiating surface. This could be increased somewhat by "finning" of some of the radiating surface.

Consider now a typical 30 watt 150 Mc/s vacuum tube design built into such a case. The receiver power requirements, including transmitter heaters, are 6.5 amperes at 13.8 volts or approximately 80 watts. The additional power requirement on transmit is 120 watts, of which 30 watts is radiated. On the basis of a 20% transmit duty-cycle, this represents an average increase of 18 watts of heat dissipation. Therefore, such a 30 watt unit on a 20% transmit duty-cycle would have to dissipate a total of approximately 100 watts or 0.25 watts per square inch of radiating surface. This might in many typical installations result in a substantial internal temperature rise. A typical figure would be 35°C for most of the chassis area. Areas of appreciably greater temperature would, of course, exist.

Consider now the case of the transistorized equipment design which is the subject of this paper. This design employs a completely transistorized receiver and a partially transistorized transmitter. Receiver power drain is 75 milliamperes at 13.8 volts with no received carrier. This rises to 350 milliamperes at 2 watts of audio output. However, because of the fact that full rated audio output is only required for momentary audio peaks, the average receiver drain certainly does not exceed 150 milliamperes or 2 watts.

The transmitter power requirements referred to the vehicle battery are as follows:

Transistorized section approximately 0.25 watt, can be neglected.

Tube section plate power 8.8 amperes or 120 watts, of which 30 watts is radiated.

Tube section continuous heater power 0.2 amperes or 2.7 watts.

Tube section "quick-heat" heater power 1.3 amperes or 18 watts.

The reference to "quick-heat" transmitter tubes will be explained at a later point.

On a 20% transmit duty cycle, all of the above transmitter drains can be divided by five, except for the continuous transmit heater power. This now gives an average heat dissipation due to the transmitter of 25 watts, or a total of 27 watts average for the combined transmitter-receiver. This gives a loading of 0.075 watts per square inch on the basis of a 400 square inch radiating surface.

Thus the transistorized design has an average heat dissipation of less than 30% of the vacuum tube design. In practice the situation is even more favorable than that indicated by the above figures because of the fact that for most mobile units the transmit duty-cycle is more likely to be 5% than 20%.

In the case of the vacuum tube design a 5% transmit cycle reduces the heat dissipation from 100 to 85 watts, a 15% reduction. For the transistor design the lighter transmit cycle reduces the heat dissipation from 27 to 10 watts, which is a 63% reduction. This is shown clearly in the graphical presentation of Fig. 1.

Thus the combination of the small size and low power drain of transistors makes possible a very compact unit which will, nevertheless, have an acceptable temperature rise in the operational environment. To further ensure against exceeding the maximum temperature ratings of the transistors, two basic precautions are taken in the mechanical packaging of the unit:

(1) The tube and transistor sections are thermally insulated from each other so that the path of least thermal resistance from the tube section is to the outer case rather than to the remaining chassis area.

(2) All heat-dissipating transistors are mounted on heat sinks which form part of the outer radiating surface of the equipment enclosure.

If the case of the unit is properly vented, so that natural convection cooling of components within the enclosure can take place, the resultant temperature rise will be appreciably less than if a non-vented case is used. For cases of comparable size the advantage is of the order of 20°C for the vented case construction. The design group responsible for this particular equipment have had many years of experience with mobile equipment designs, employing both vented and non-vented cases. This experience has shown that for almost all applications there is no loss of reliability due to venting of the case, if all relays are sealed in dust-tight enclosures.

In a design combining transistors and tubes effectively, all the advantages of case venting can be realized if the venting is restricted to the vacuum tube portion of the unit only. Moreover, a dust-tight inner partition between the vented and non-vented portions of the unit can also perform part of the function described above as thermal insulation between the transistor and vacuum tube sections of the equipment.

The basic design is suitable for either underdash or trunk-mount applications. However, for the reasons discussed previously which

included a more favorable thermal environment, in actual practice the underdash mounting is recommended whenever possible.

The equipment circuitry is divided into the three main cases of receiver, transmitter and power supply.

The receiver is a double conversion superheterodyne having IF frequencies of 8 Mc/s and 455 Kc/s. The basic selectivity required at both IF frequencies is furnished by lumped, sealed filters. These filters are factory aligned and will not require field adjustment during the life of the equipment. This feature minimizes the number of tuning adjustments.

Fig. 2 shows a block diagram of the receiver. The front end comprises two stages of amplification at signal frequency followed by the first mixer. There is no amplification at 8 Mc/s and the signal is fed from the first mixer into the second mixer via the first IF filter. The bulk of amplification is done at 455 Kc/s with two amplifier and three limiter stages. The limiters are R-C coupled and the last limiter stage is saturated by front end noise at all times.

The discriminator used is the Foster-Seely circuit. Recovered audio is fed into a de-emphasis network, which is followed by an audio amplifier delivering 2 watts of audio output. The output stage operates in class B to keep standby battery drain at a low value.

Noise from the discriminator is fed into a squelch amplifier, followed by a selective network, a squelch rectifier, and a DC amplifier. Control voltage from the DC amplifier is fed into the first audio amplifier transistor.

One of the more difficult problems in transistorized receiver design is that of intermodulation. Because of the small signal handling capability and nonlinear transfer characteristics of the transistor, intermodulation distortion is more pronounced in transistorized receivers than in vacuum tube receivers.

In order to reduce intermodulation distortion, it is necessary to reduce signal levels before the stage where the interfering signal is generated. In this design, gain reduction is achieved by applying forward AGC to the two VHF amplifiers. The two signal frequency amplifier transistors are of MESA construction and application of forward AGC is recommended by the manufacturer. Besides a gain reduction, forward AGC also increases signal handling capability, thus providing more linear operation, and reduces collector swing.

The number of transistors used in the receiver is twenty, distributed as shown in the block diagram of Fig. 2. The design is such that an adequate gain reserve exists in all sections of the receiver, and the normal commercial spread of transistor characteristics will in no case deteriorate the receiver performance outside of its specification limits. This last factor is of particular importance when field replacement of transistors is necessary for maintenance reasons.

The performance of the equipment meets, and in many cases exceeds, all requirements of the current applicable specifications of the FCC, the Canadian Department of Transport, and the EIA of both countries. In some aspects, such as receiver sensitivity, there is an appreciable improvement over the above specification requirements. The overall sensitivity for a 12 dB SINAD ratio is better than 0.3 microvolts at the design centre supply voltage of 13.8 volts. Over a supply voltage variation of ± 20% the sensitivity does not deteriorate below 0.4 microvolts.

Fig. 5 shows the variation of receiver sensitivity with supply voltage.

The transmitter uses both transistors and tubes, in order to keep the equipment standby drain to a minimum. Fig. 3 shows a block diagram of the transmitter.

Transistors are used in all low level stages and this portion includes the oscillator, modulator and first frequency multiplier and, of course, the audio amplifier with its modulation limiter. The transmitter is designed to be used with a dynamic microphone having a built-in transistor pre-amplifier.

The oscillator operates in a modified Colpitts circuit. The output from the oscillator is fed via a small coupling capacitor to the modulator. Fig. 4 shows a simplified circuit diagram of the modulator. This is basically a tuned circuit whose resonant frequency is varied by modulation. The tuned circuit consists of a fixed inductance L in parallel with a variable capacitance C; in this case a silicon voltage-variable capacitor (Varicap).

Because of the small value of coupling capacitor by which energy from the oscillator is fed to the tuned circuit, a change in resonant frequency of the tuned circuit results in a change in phase of the voltage across it.

In order to keep modulation distortion at a reasonably low level, in the case of wide-band operation (i.e. 60 Kc/s channel spacing), a frequency multiplication of 24 times was chosen. Modulation distortion does not exceed 4% for 10.5 Kc/s deviation at 1000 cycles. This figure includes distortion in the audio circuitry.

The modulator is followed by a transistor

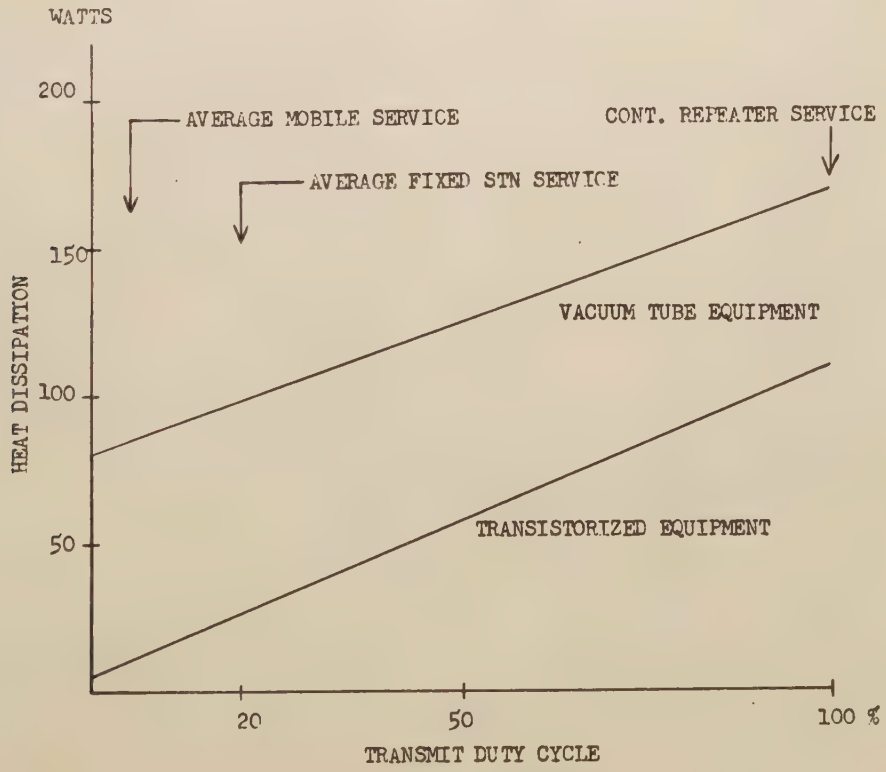
frequency doubler. The rest of the multiplier chain comprises two frame-grid pentodes and a push-push doubler-driver. The design of the doubler-driver and power amplifier stages is based on the new "quick-heat" version of the 6360 and 6252 dual tetrodes. These tubes only have heater power applied when the push-to-talk switch is operated. However, 70% of rated power output is available in one second. This feature enables full advantage to be taken of the low drain of the transistorized receiver and yet permit the transmit function to be instantly available when required.

The transmitter has adequate drive reserve to permit communication with supply voltage as low as 20% below design centre. Fig. 5 shows the variation of transmitter power output with supply voltage.

It would seem natural to use only "quick-heat" tubes and transistors throughout the transmitter design. However, low level "quick-heat" tubes are not yet available. The two frame-grid tubes are used because of their high power gain and the ruggedness inherent in the grame-grid type of construction.

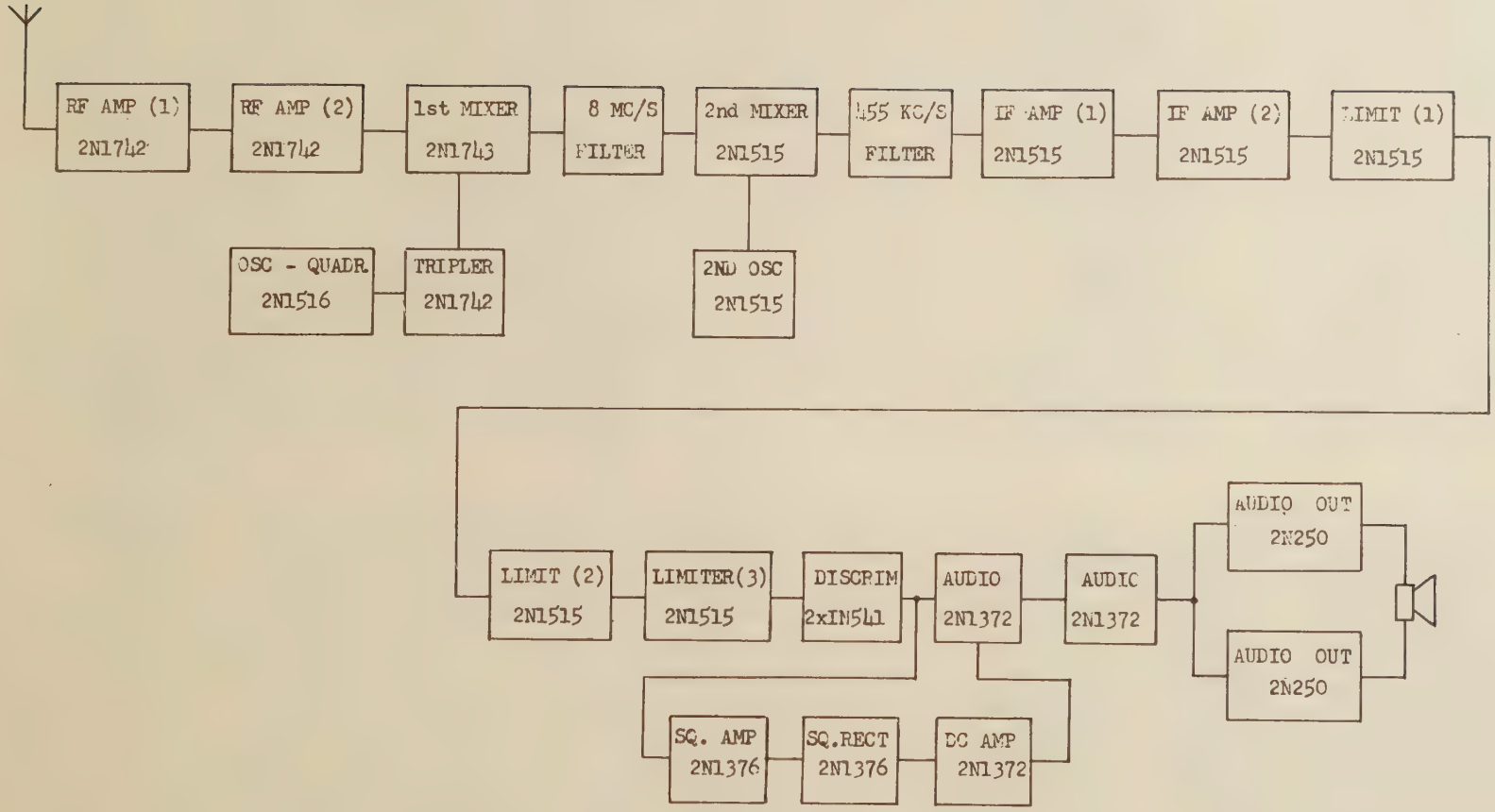
Consideration has been given in both receiver and transmitter design to simple methods of multi-channel switching. Up to eleven channels can be accommodated with maximum channel separation of up to 1 Mc. In multi-channel equipment a single crystal oscillator is used in both the transmitter and receiver. Crystals are switched by means of standard wafer switch with the unused crystals shorted out. Individual netting adjustments are provided for each crystal used.

The writer wishes to acknowledge the assistance of Mr. W. Ornstein in the preparation of this paper and the efforts of Messrs. Ward, Willmott and Hansen of the Systcoms Engineering Department who assisted in the development of the unit.



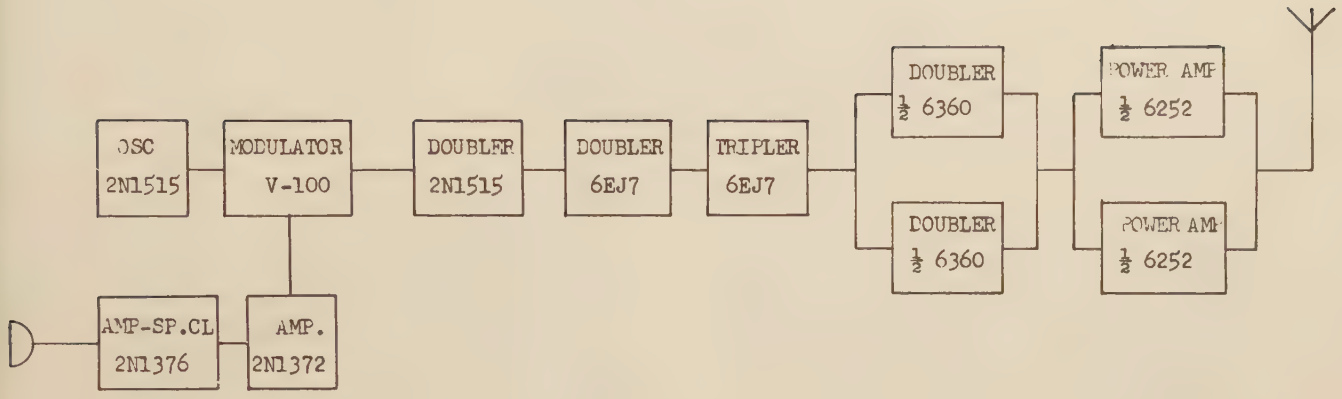
HEAT DISSIPATION VS TRANSMIT DUTY CYCLE
30 WATT FM RADIOTELEPHONE

FIG. 1



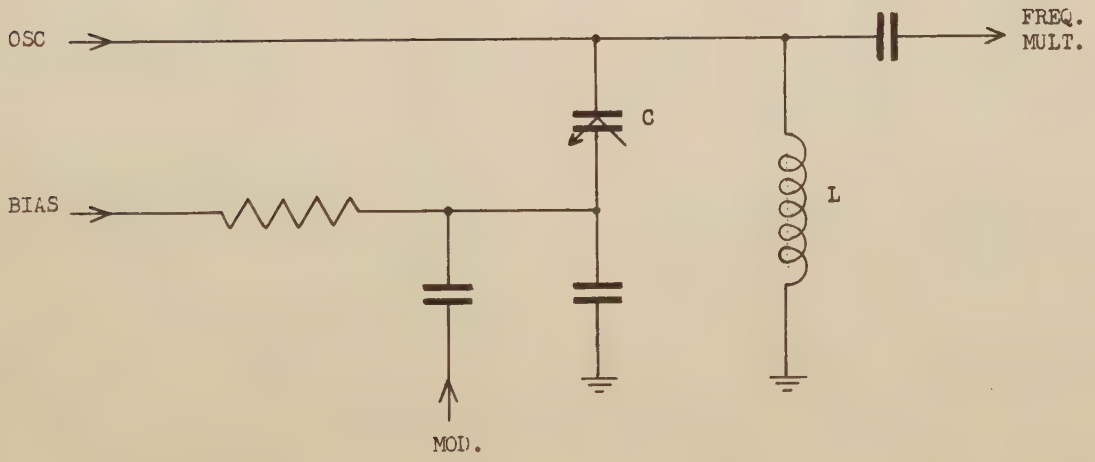
RECEIVER BLOCK DIAGRAM

FIG. 2



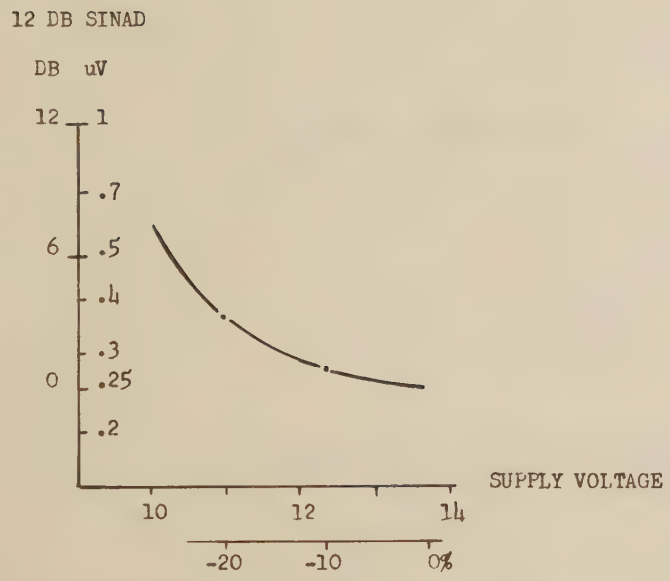
TRANSMITTER BLOCK DIAGRAM

FIG. 3

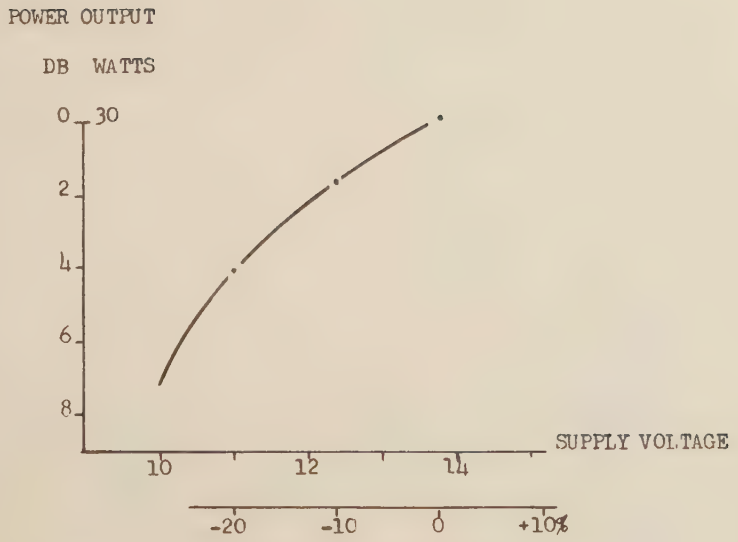


SIMPLIFIED CIRCUIT DIAGRAM OF PHASE MODULATOR

FIG. 4



RECEIVER SENSITIVITY VS. SUPPLY VOLTAGE



TRANSMITTER POWER OUTPUT VS. SUPPLY VOLTAGE

FIG. 5

150-MC Personal Radio Signaling System

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Summary

An experimental 150 MC personal signaling system has been set up in New York City to evaluate over-all technical performance and explore subscriber reactions to the system. The system includes pocket receivers equipped with tuned reeds and central office arrangements adapted for direct customer dialing. The paper describes the system in over-all terms, and tells how it was engineered. It also compares this system with present 35 MC systems and discusses traffic and radio transmission problems.

1. Introduction

An experimental trial of a 150 MC personal radio signaling system known as the BELLBOY system was started in New York City in October, 1960. The service given to customers is similar to that provided by Telephone Company 35 MC systems[1,2,3] now operating in several smaller cities. The new system, however, has a much greater traffic capacity, uses receivers of greater selectivity and sensitivity and includes direct customer dialing.

Basically, this system extends the telephone bell to the customer's pocket. Each customer carries a pocket radio receiver containing reeds tuned to specific audio frequencies. This allows him to be selectively signaled. Three transmitters installed in the lower part of Manhattan give coverage in practically all locations below 59th Street. Central office arrangements are provided which accept calls dialed in, and in response cause the specific signal of the customer being called to be radiated three times on the air.

When this signal reaches the customer's set, it causes the set to emit an alerting sound. The customer now knows that his office has received an important call and he goes to the nearest telephone and calls back to get his message.

The systems now in service at 35 MC give broadly this same kind of service. As will be pointed out later in this paper, the limitations of the 35 MC system which include receivers of lower selectivity and sensitivity and slower signaling speed severely limit its usage in big cities. In addition there is a more fundamental problem due to the limited number of common carrier frequency allocations available at 35 MC. These prevent growth of 35 MC systems to more than a few hundred customers in many cities. These limitations are the main reasons for proceeding with the development of the 150 MC system. Some comparisons of the environments of the two systems are given in Section 3.

An interesting general feature of this experimental trial is that some of the receivers are provided with replaceable batteries and some with rechargeable batteries. The latter type receiver requires that the battery be recharged every night in a unit provided for that purpose but this removes the necessity for getting a fresh battery to the customer every few weeks.

In the early planning of this project it was apparent that there were two major technical problems. One was the need for a highly sensitive pocket receiver with a code responsive device. The other was the need for more accurate knowledge of radio transmission loss into buildings.

A very sensitive, stable and selective receiver has been developed by Bell Telephone Laboratories to operate in the 150 MC range. This receiver will be described in more detail in a forthcoming paper but some of its characteristics are covered later in this paper. A receiver capable of giving service at 35 MC has been developed by an outside supplier.[4]

It would not have been possible to intelligently plan this system without knowledge of radio transmission loss into buildings. For this reason an extensive test program was set up early in this project and these measurements are covered in an earlier paper by Mr. L. P. Rice[2].

2. Over-all System Plan

Operation of the BELLBOY system can be understood by tracing the path of a call as it progresses through the various parts of the system which are pictorially represented in Figure 1. When there is an urgent need to reach the customer who is out of the office his secretary dials his number which might be BB 5-4654, and listens. She hears a momentary ringback, followed by a warbling tone, which signifies that the number has been received, checked and stored in the central office equipment. She may now hang up but if instead she listens a few seconds longer she wil hear a verbal announcement that her BELLBOY number will be signaled. Within a period ranging from a few seconds to about a minute the signal is put on the air and the customer's set emits a steady beep. The customer now depresses a button on the receiver to stop the beep, goes to the nearest telephone, in this case a pay station, and calls his office to get his message.

Central Office Arrangements

What actually happened right after the secretary dialed was typical of many dialed telephone calls. The first three digits of the number, BB5, correspond to a central office designation and normally would represent the one which serves the called party with incoming service. In BELLBOY service the counterpart of the terminating central office is actually the J-1 terminal which couples the wire plant to the radio portion of the system. All originating offices are wired to recognize the code BB5 and set up a proper route through a tandem office which has the ability to accept digits in any form. It then forwards them as dial pulses since the present J-1 is arranged to accept only dial pulses. Figure 2 illustrates the functions of the J-1 terminal.

When the last 4 digits, 4654, are spilled into the trunk they are received by dial pulse registers. A number checking circuit then verifies that the number is actually within the number blocks containing the valid codes. A connecting circuit next transfers the 4 digits from the register to a reed switch store on a 2 out of 5 basis.

This number along with those due to additional calls stays in storage until called for by the storage control circuit. This occurs when the radio transmitters are available. At this time the translator uses the information in the stores to connect three of the 32 tone generators in the 36A oscillator to the transmitter control circuit. There the tones are amplified and fed to the three radio transmitters in the trial system. All transmitters are turned on and the presence of the modulating tones and RF carrier are verified by "sniffer" circuits at each one. A timing circuit then maintains the modulation for about 0.5 seconds and then inserts a pause of 0.5 second before the next signal. Each individual code signal is sent three times to guard against dead spots.

In principle there are 4960 possible codes, when choosing three at a time from a universe of 32. In this system the translation, from the 4 digit decimal number assigned to each receiver to 3 tones chosen from 32, is made more simple and economical by using only 3200 of the possible codes. More codes could be provided by introducing a more complicated translator or by increasing the number of tones.

BELLBOY system numbers are served on the basis of groups that arrive during time intervals which are slightly over one minute long. This arrangement permits an economical design, but results in minor delays which can range from one second to a little over a minute, with an average value of about one half minute. A four digit number spilled into the terminal is transmitted immediately if there is no other number in storage. That number retains exclusive use of the radio transmitters until it has been radiated the third time about 60 seconds later. Meantime arriving numbers must wait for service. Then they are radiated in sequence, each taking about one second to

process. After the third transmission, each is cleared from storage and when the last to arrive has been cleared, the next wating group is served in similar fashion.

Figure 3 is a time diagram illustrating the foregoing, for a moderately loaded system. It is assumed that at time t=o the control circuit is just starting to serve calls 1, 2 and 3 in group A. The third transmission will be completed 63 seconds later. During that interval calls 4-7 arrive in storage and wait there for intervals ranging from 62 to 6 seconds. At 64 seconds after t=o call 4 is served for the first time. The figure also shows the arrival and service of group C. It will be clear that the maximum time interval between the arrival of a call in storage and the completion of the third transmission is (120+n) seconds where n is the number of calls in the immediately preceding group.

Each code which is transmitted comprises 3 audio tones, each tone being applied so as to produce a carrier deviation of 1.3 kc. The tone sources are crystal controlled transistorized square wave generators. They produce odd multiples of 7.5 cycles per second beginning at 517.5 cps and ending at 997.5. These square waves are then filtered to produce sine waves. Two frequency groups, a low and a high, are formed by omitting the center frequency 757.5 cps. In the present system each code consists of two frequencies from one group and one frequency from the other. It will be clear that second order products generated in the over-all system fall outside the present range of tones and would always fall between tones if the range were extended by adding more odd harmonics of 7.5 cps. Although some third order products can fall on operating frequencies they will be too low in level to introduce errors.

Pocket Receiver

The pocket receiver will be covered in some detail in a forthcoming paper but a brief general description of it will be of interest. It is a highly sensitive and selective radio receiver using 10 transistors and 3 vibrating reeds. Two views of a receiver are shown in Figure 4. Reeds are available for each of 32 frequencies produced by the 32 tone generator and any 3 may be inserted into any receiver.

The receiver proper consists of 2 stages of RF amplification at 150 MC, an oscillator with diode mixer and 3 stages of IF. Six transistors are used for these functions. An additional transistor is used for the limiter and two for an amplifier to drive the reeds. A final transistor provides audio signaling tone to a small transducer which produces the beep. An interesting feature of the receiver is that it uses only one frequency conversion with the IF at about 5.5 kc. This feature has allowed an economical receiver design and provides very satisfactory operation for reed signaling.

The reeds will also be described in more detail in a subsequent paper. Each reed is a highly stable tuning fork structure with a bandwidth of one cycle. They are similar to those used in the trial of reed signaling in mobile radio at Richmond, Virginia, some years ago.[6,7] The new miniature reeds [8], however, occupy only about 1/7 the space, have about 1/6 the weight and require 1/5 the power of those used at Richmond.

Integrated Operation

The operation of the terminal, described above, assumed that the radio channel was assigned solely to signaling, as is the case for the trial. The terminal, however, has been designed so that it is possible to operate on a channel also used for mobile telephone service. In this "integration", use of the radio channel is alternated between the two services with mobile telephone service having priority. BELLBOY service numbers which have been transmitted once will be required to wait more than the normal interval if a telephone call originates before their second transmission. This can result in intervals of variable duration between first and second or second and third transmissions. As this period of time increases the customer might become confused as to whether he is receiving a repetition or a new call. For this reason a timing feature is provided in the control circuit to clear from storage any calls

which have been served whenever this interval becomes excessive.

3. Comparison of 35 MC and 150 MC Environment

It is well known that long range "skip" interference has necessitated dividing the North American continent into zones with only one or two 35 MC common carrier frequency allocations to each zone. The nature of skip interference is such that although the frequency allocation may be reused at distances up to a few hundred miles, it cannot be reused at distances from roughly 1000 to 3000 miles. The map in Figure 5 indicates this well known zoning plan as used for 35 MC mobile telephone service. In general, this means that a transmitter of reasonably high power such as 250 watts must be assigned only to its own zone frequency. Otherwise, occasional skip interference from its radiation will cause serious interference to mobile telephone receivers in distant zones. It is rather significant and of interest, however, that such interference which amounts to free space transmission is usually no more than about 20 db above a usable signal.

All BELLBOY receivers are at least 20 db less sensitive than mobile telephone receivers because of their small antennas. Thus at 35 MC there would probably be no interference problem into BELLBOY receivers from a distant zone. On the other hand it would not be allowable to transmit signals at 250 watts on a channel assigned to another zone because of interference into mobile radio receivers.

Reducing transmitter power 20 db or more does not appear to be a practical solution since even with 250 watt transmitters and high performance receivers the range into modern steel reinforced buildings is only about 1 1/2 miles and into big city streets about five miles (Section 5 covers these matters in more detail).

These factors sum up to the conclusion that in the majority of cases it is only practical to give BELLBOY service at 35 MC on the regular zone channel in any one area. This means that if it is desired to give such service in an area already having highway mobile telephone service, it is necessary to integrate BELLBOY service with mobile telephone. This can be readily done but it places a severe limitation on the possible number of customers and the grade of service.

However, there is an unexpected dividend from this restriction to only the zone channel, which is illustrated in Figure 6. In most zones one of the interior channels is used, thus there will ordinarily be no high-powered radiation in that zone on any nearby channels. This allows the use of a relatively nonselective receiver. A problem may arise, however, if there is potential interference from nearby channels assigned to other than common carrier services. One example is when an edge channel is used as shown in Figure 6.

These factors permit the satisfactory use of a super-regenerative receiver to give service in many small to moderate sized cities throughout the country. About 20 systems are now in service. Such a receiver is naturally substantially simpler and, therefore, cheaper than a more selective receiver. As a matter of fact, it is apparent from Figure 6 that in most situations there is no incentive to use a more selective receiver, as long as the present allocation plan is used in the 35 MC frequency range.

On the other hand, it is also apparent that in order to provide adequate service in the areas where there are large numbers of potential customers, a system is needed capable of operating where there are more channels available. Figure 7 indicates

the situation in the 150 MC band. Here there are 11 channels assigned to common carrier usage and since there is no long range interference problem, all of these channels are available in any area.

In some highly settled areas it may be necessary to use almost all of these channels for mobile telephones. In such cases it may be necessary to provide BELLBOY service on an integrated basis. In many areas, even the thickly settled ones, however, it will be possible to set aside at least one clear 150 MC channel for signaling. As pointed out in Section 4, a clear channel provides a large customer capacity. In addition the 150 MC system has a 4 to 1 speed advantage due to the use of simultaneous tones instead of the sequential arrangement used in the 35 MC receiver.

These advantages, however, are obtained at a considerable cost. As indicated in Figure 7, the 150 MC receiver selectivity must be good enough to allow adjacent channel operation. This, of course, also implies a high degree of frequency stability.

4. Traffic Considerations

The central office equipment in the J-1 terminal is designed on a flexible basis so only the equipment needed for a particular situation will be installed. When fully equipped the system will accommodate a maximum of 3200 4 digit numbers. These fall in the following number groups:

1000 - 1999
2100 - 2699
3000 - 3999
4100 - 4699

The number of BELLBOY service customers, N, that can be served from a single radio channel depends on the amount of traffic which they generate. Since the holding time, h, of each call is fixed at approximately 3 seconds by design, the calling rate during the busy hour, c, becomes the controlling factor. Experience to date with the 35 MC system indicates only 0.4 calls per customer per day and approximately 0.1 call per hour in the busy hour. However, in the New York trial the corresponding figures have been about twice as high. The following expression can be used to find the RF channel capacity,

$$N = \frac{3600}{c.h} E$$

where 3600 = seconds per hour and E is an efficiency factor Taking E = .8, c = 0.2 and h = 3 seconds it is found that

$$N = \frac{(3600)(0.8)}{(0.2)(3)} = 4800$$

It thus appears that for this calling rate the radio channel would not be fully loaded by the 3200 codes included in the present system. It is possible that the calling rate will vary from one city to another, depending on the characteristics of the principal users of the system.

The number of registers and storage units needed is also affected by the calling rate. Registers can be installed on a unit basis while stores come in blocks of 10. The present maximum is 10 registers and 40 stores.

The holding time for an incoming trunk and register circuit depends somewhat on the customer. In cases where the call comes through tandem and the customer hangs up promptly upon hearing the warble tone signifying acceptance of the call, the holding time hr may be as short as seven seconds. In cities where the customer dials directly from a step-by-step office and waits for the complete voice announcement the holding time may increase to about 12 seconds. Taking the lower figure of 7 seconds and assuming c=0.2, N=3200 the average number of registers in use during the busy hour would be

$$a_r = \frac{ch_rN}{3600} = \frac{(0.2)(7)(3200)}{3600} = 1.24$$

This average figure which is derived by assuming that all calls come in at a uniform rate is defined as the load in "erlangs". Standard tables are available[9] which show the grade of service for a given load when various numbers of the given device or facility are available.

From such a table it is apparent that the provision of five registers would insure a good grade of service in which the probability of being delayed due to lack of a trunk and register would be less than 0.01. Assumption of a 12 second holding time would increase the load to 2.1 erlangs. This would require seven registers for approximately the same grade of service.

In order to develop the holding time for a storage unit it is necessary to recognize that the basic time interval during which new calls arrive in storage, has a duration equal to the maximum service time for the immediately preceding group of calls. This is 60 seconds plus the time needed for the third transmission of the n old calls being serviced. Since each transmission of a call requires one second, the basic acceptance interval is thus (60+n) seconds, during which n' new calls arrive in storage. The average value of the acceptance interval is thus $\frac{60+n}{2}$ seconds. Each new call has its third transmission completed in 60 seconds and so, the average transmitting time for the new calls is

$$60 + \frac{n'}{2}$$

The average storage holding time is the sum of these two times, i.e.,

$$90 + \frac{n}{2} + \frac{n'}{2}$$

or about $90+\bar{n}$ where $\bar{n}$ is assumed to be the average n.

It is of interest to develop the load factor for stores but in order to do so, we must determine what $\bar{n}$ is for various calling rates.

The average number of stores needed, $\bar{n}$, depends on the calling rate and holding time, as before. Substituting the value $(3t + \bar{n})$ for the holding time, where t is the interval in seconds between successive transmission it is found that

$$\bar{n} = \frac{cN\,(3t+\bar{n})}{3600}$$

which is the same as the load expressed in erlangs. Solving gives

$$a_s = \bar{n} = \frac{3\,tc\,N}{3600-cN} \quad \text{erlangs}$$

This is not a rigorous solution but is believed to be a reasonably close approximation.

The following table shows the load offered to the storage system for 3200 customers and various values of calling rate c and time between signals t.

Calling rate in busy hr. c	Load offered a_s, erlangs		
	t=20 sec.	t=25 sec.	t=30 sec.
0.30	21.7	27.3	32.5
0.20	13.	16.3	20.8
0.10	5.9	7.4	9.4

It is apparent that with 3200 customers, 40 stores will be sufficient if the calling rate is 0.2 and nearly sufficient for a calling rate of 0.3. If desirable the load could be reduced by reducing the interval t between transmissions. The figure of 30 seconds has been used during the trial but further experience may indicate that this can be reduced somewhat. It should also be noted that the present system is more than adequate for a calling rate of 0.1 which has been found in systems operating in other cities. A more rigorous analysis of this case is beyond the scope of this paper.

The tone generators are designed on an individual basis, each unit being a replaceable printed circuit board. In small installations it is possible to substitute a resistance for some of the generators and equip only those required for the N codes in the initial system. It can be shown that the number needed

is approximately 2 $N^{\frac{1}{3}}$ +1 generators. A new installation having 300 customers could thus start by equipping 16 generators. As growth occurs additional units can be inserted in the mounting rack.

A study of the calling habits of customers in the New York trial was carried out by slaving a 20 pen recorder to the relays controlling connection of the tone generators. These recordings furnished the data for the estimates, used earlier for the average calling rates during the 5 day working week. There is some calling on Saturday and Sunday, but at a greatly reduced rate.

5. Radio Transmission Considerations

The key element in transmission performance of the BELLBOY system is the pocket receiver. The 150 MC receiver is capable of triggering on an electrically connected input signal of about one microvolt and is thus comparable in electrical performance to receivers now being used for mobile telephone. In addition, its selectivity is 80 db at a frequency 30 kc away from the carrier, which is also comparable to mobile telephone requirements.

Any pocket receiver, however, suffers a very substantial loss in effective sensitivity due to the fact that the antenna is small compared to a half wavelength. The antenna in this receiver is a ferrite stick which has been found to give about the best performance of any tested so far. Even this antenna, however, has a loss of over 20 db compared to a half wave dipole.

One of the problems in engineering this system was to find a reliable and simple method of measuring the performance of the small receivers. Two types of measurement are important. One is to determine sensitivity in free space and the other to determine sensitivity when the receiver is carried in the normal manner near a person's body.

Early tests were made in an open field at Holmdel, New Jersey, to make absolute determinations of free space sensitivity and these sensitivity figures were then compared to typical sensitivity on the body. Sensitivity is defined as the field in db above 1 microvolt per meter required to just trigger the receiver.

Figure 8 shows the relative response of a typical receiver when worn in a man's outer coat pocket as compared to its sensitivity in free space. As might be expected, there is quite a large variation depending on which way the receiver or man with receiver is facing relative to the transmitter. It is of interest that in some orientations the man provides gain. Apparently, a ferrite stick couples electrically to some extent to the body thus effectively using it as an antenna. In other orientations, however, the body provides shielding. It has been assumed for engineering purposes that the average sensitivity of a receiver would be used for estimating range. This seems reasonable since it appears equally probable that a person may be facing in any direction when he is signaled. It is of interest that the average sensitivity of this receiver is 35.8 db on the body and 35 db in free space.

It is apparent that measuring receivers in an open field is a clumsy and time-consuming process so experiments were made with various methods of measuring receivers in the laboratory. The most compact arrangement is a jig where the receiver may be placed in a plastic structure so that it couples closely to a fixed pick-up coil. Although this method is satisfactory for rough checking it was found that its accuracy left something to be desired. For this reason another method was worked out shown in Figure 9. This involves the use of a short section of waveguide which is big enough to transmit 150 MC with very little attenuation. Although this arrangement, which has been nicknamed the "bear trap" is somewhat bulky, it can be set up in a moderate-sized room and has been found to give reproducible results.

As indicated, the receiver is supported in a piece of foam plastic

about 4 feet away from the transmitting loop and in the center of the waveguide. The combination of space cloth and metallic termination at the right has turned out to be quite effective in holding down the standing wave ratio which is about 1.2 . It thus turns out that the receiver is in a fairly uniform vertically polarized electric field and the measurements are not overly critical as to receiver position. Figure 10 shows a correlation of free space measurements in an open field and measurements in the "bear trap" for about 30 receivers.

Using the figure of 36 db sensitivity it is possible to predict range using the technique described in Mr. L. P. Rice's paper[5].

The following table summarizes the figures used in this estimate in the same manner as shown in Table 2 of the Rice paper.

A - Receiver sensitivity in db above 1 microvolt per meter	36
B - Corresponding minimum usable power in dbw in a whip antenna	-116 dbw
C - Radio transmitter power in dbw (dipole)	24
D - Maximum allowable path loss in db (C-B)	140
E - Building loss in db for 78 per cent reliability	31
F - Equivalent median loss allowable in streets - db (D-E)	109

For convenience, Figure 11 is reproduced from the Rice paper[5] which shows the building loss in db referred to median field in the streets. Figure 12 also reproduced from the same paper indicates path loss between a half wave dipole and a quarter wave whip in the streets. Most of this material originally appeared in a paper by W. R. Young[10]. From Figure 12 it is apparent that 109 db median path loss in the streets corresponds to a range of about 1.6 miles. Thus, we would estimate a little over a mile and one-half range into buildings with this receiver, with a 78 per cent chance of success in one try.

Similarly by interpolating on Figure 12 we would estimate a range of about four and one-half miles in the streets for the path loss to be less than 140 db for 78 per cent of the cases.

The use of 78 per cent reliability for one try ties in with the planned reliability of BELLBOY service of 0.99 or better. Thus by engineering a system so that the probability of receiving a single transmission is 0.78 the probability that failure will occur three successive times is $(0.22)^3$ or one per cent. Thus the probability that at least one transmission will be successfully received is (1-.01) or 99 per cent.

Our experience has indicated that this estimate of one and one-half miles range into buildings and four and one-half miles in the streets is reasonably correct. Obviously several transmitters will be needed to cover a big city.

It has been found possible to transmit simultaneously from transmitters with overlapping coverage provided radio frequency is controlled to an accuracy of one part per million, i.e., 10^{-6}. This holds the operating frequency of 152.780 MC to ±153 cps, and keeps beat notes in the receiver below the lowest tone in the coding system.

Laboratory tests have shown that simultaneous reception of two signals produces a slight gain in receiving provided the phases of the modulating tones differ by less than 70°. This is easy to assure and modulation of the three transmitters in the trial is well within this limit. It has not been possible to discover any effect, either positive or negative in field testing. If, however, the phase of the modulation at two

transmitters differs by more than 90 degrees there is some penalty. When the difference is 130 degrees the receiver will not operate if the two signal strengths are within 4 db of each other. At 180 degrees the corresponding figure is 6 db. These test results were obtained when the frequency difference between the two carriers ranged from 20 to 300 cycles per second.

Figure 13 shows the locations of the three 250 watt transmitters in lower Manhattan. These give coverage in every street location tested below 59th Street and in practically all buildings. As might be expected, however, there are a few dead spots. These occur particularly in the lower floors and the interior portions of large buildings which have considerable metal in their construction. One example is the interior of the lobby of the Waldorf-Astoria, while another is part of Grand Central Terminal.

One customer also found that he could not receive signals while he was in the hold of a ship docked in Brooklyn. This does not seem surprising as a ship interior is probably nearly the equivalent of a shielded room.

In general, it appears that the estimated range figures can be used for most commercial situations. It may turn out, however, that additional low power transmitters will be needed to cover certain important buildings such as hospitals or large office buildings.

Obviously the short range of this system means that quite a few satellite transmitters will be needed in the larger cities. The satellites would have to be located fairly close together in places like downtown Manhattan but can be spread out considerably in residential areas. The short range, however, is not entirely a disadvantage. It will allow a channel frequency used exclusively for BELLBOY service to be reused at much shorter distances than with mobile telephone.

A potential interference problem exists, however, from the use of satellite transmitters. This comes about when a mobile telephone customer on an adjacent channel drives his car in the near vicinity of the satellite transmitters. In this case the mobile customer's receiver may be subjected to a strong field compared to the field he receives on the desired channel from a distant fixed transmitter. Preliminary tests, however, indicate that trouble can be avoided on this score.

In the first place the fixed transmitter used on the adjacent mobile channels can be coordinated with the BELLBOY system so that it will always be turned on if the BELLBOY transmitters are radiating. This will guarantee that there is at least some field present near every satellite transmitter. A further improvement in this situation can be effected by the use of directive antennas for the satellites. These may be stacked dipoles or some similar arrangement providing directivity in the vertical plane so that excessively strong fields just below the satellite transmitters are avoided.

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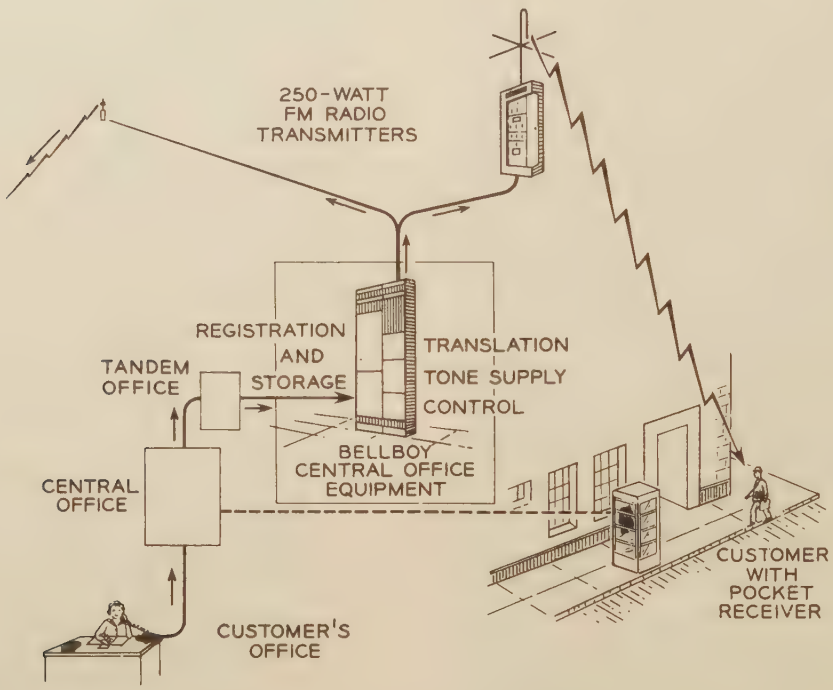

Fig. 1. Over-all plan of operation.

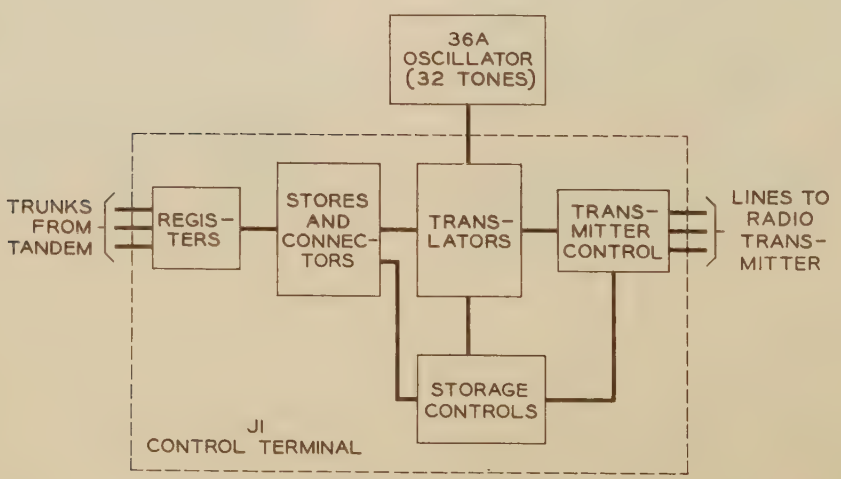

Fig. 2. Central office arrangements.

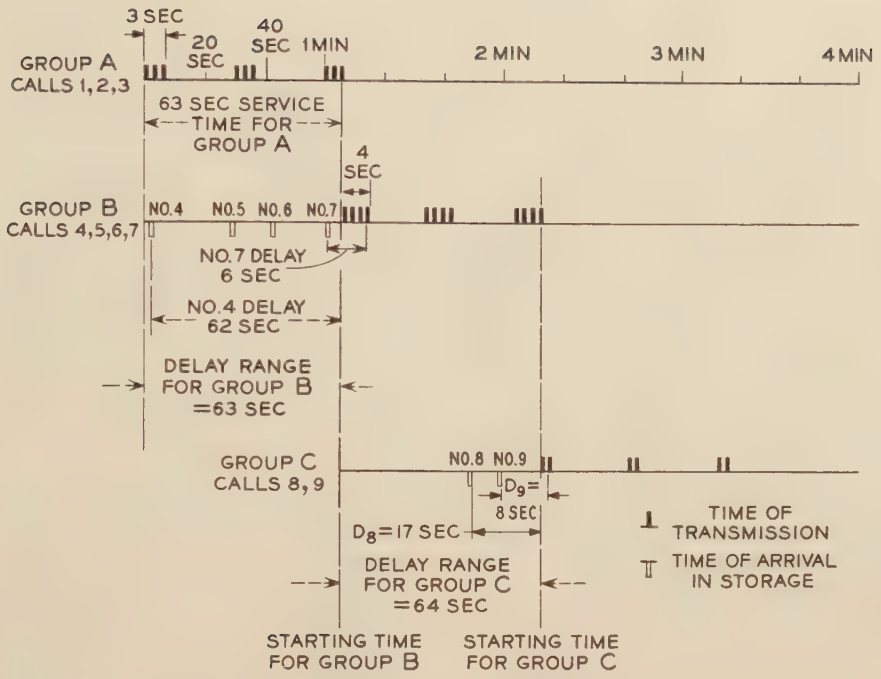

Fig. 3. Time diagram of BELLBOY system calls.

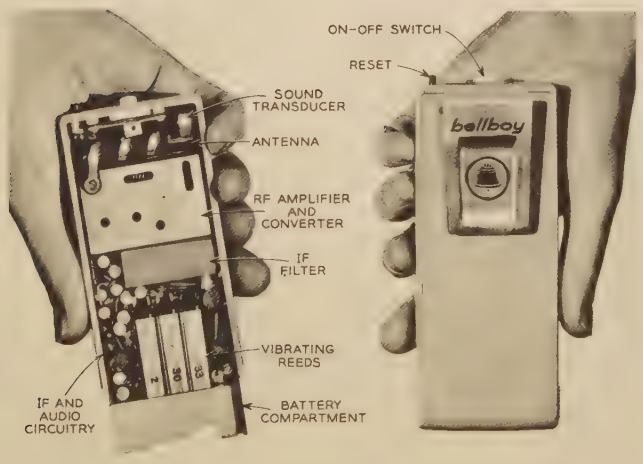

Fig. 4. 150-Mc BELLBOY pocket receiver.

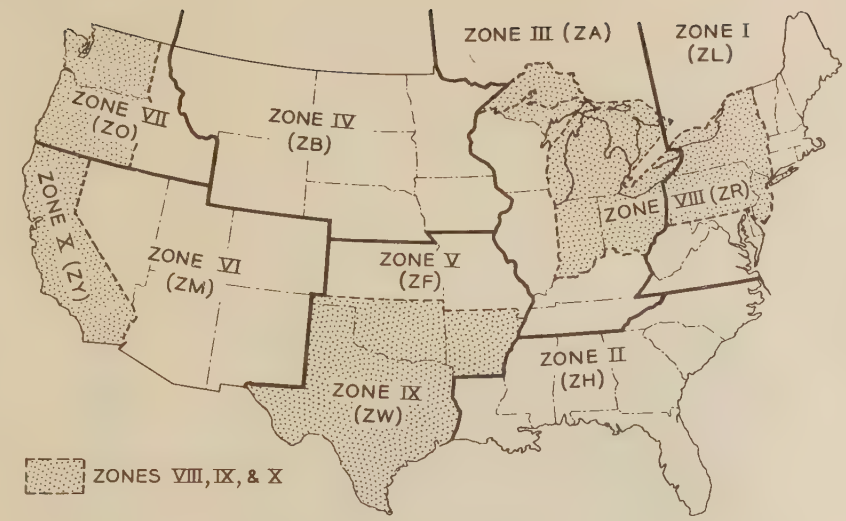

Fig. 5. Common carrier frequency zoning plan for 30-44-Mc Mobile telephone service.

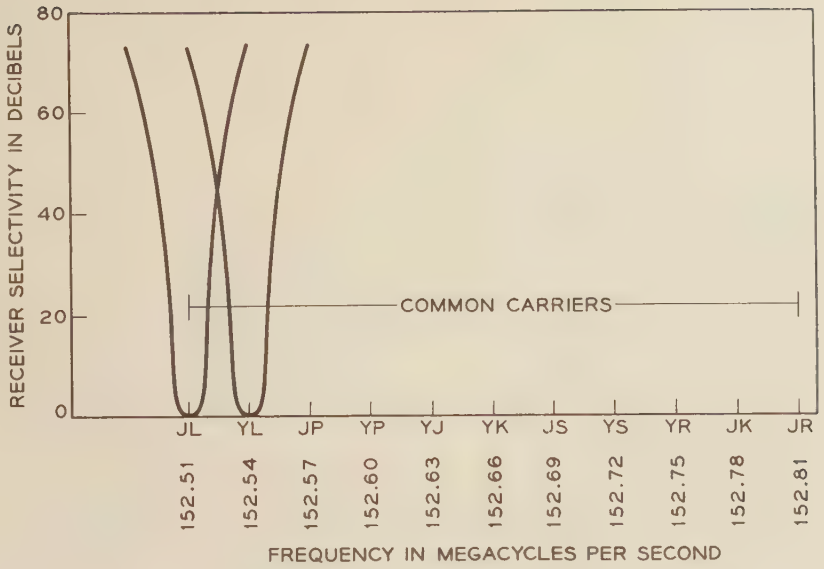

Fig. 7. Factors in channel usage at 150-Mc.

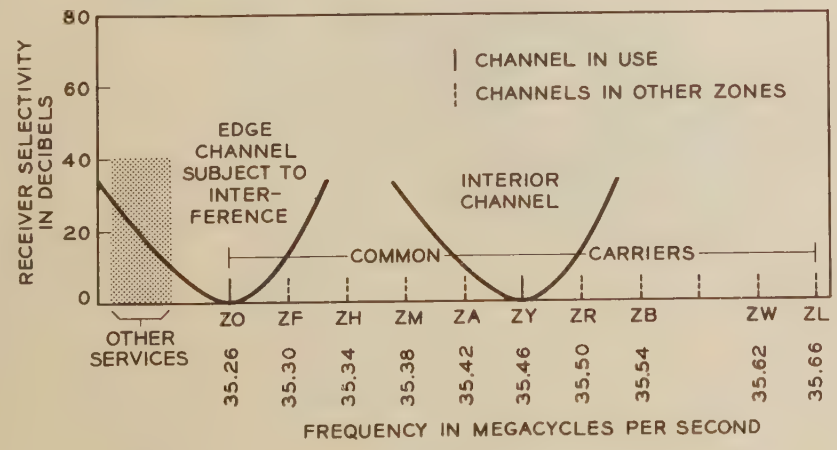

Fig. 6. Factors in channel usage at 35-Mc.

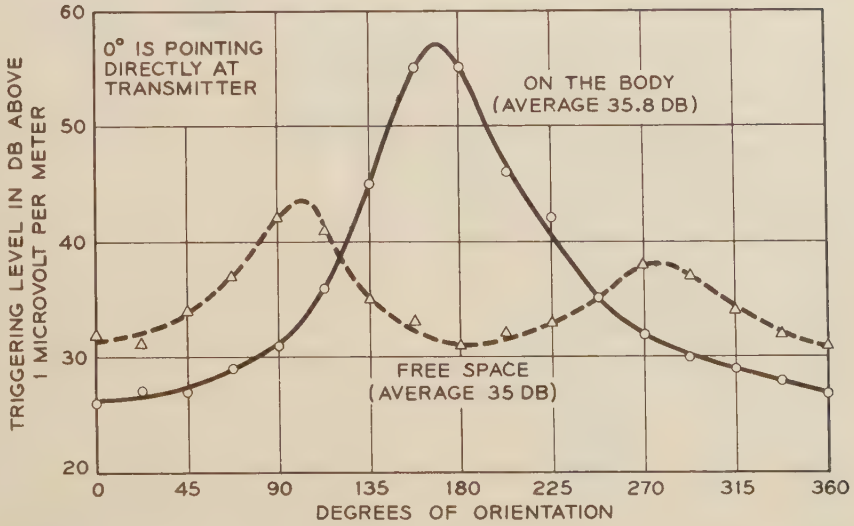

Fig. 8. Relative response of receiver in free space and on the body.

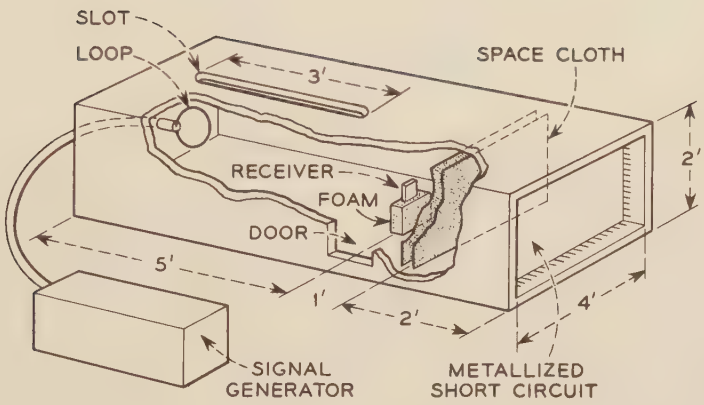

Fig. 9. Method of measuring pocket receivers using 150-Mc Waveguide "Bear Trap".

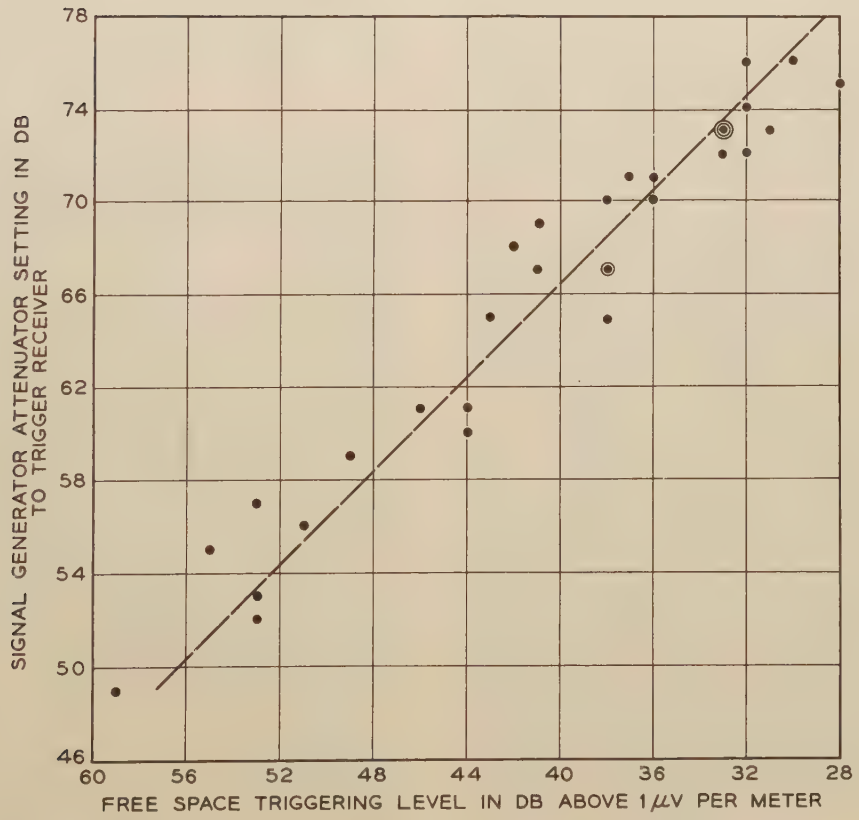

Fig. 10. BELLBOY receiver measurements in the "Bear Trap" vs free space.

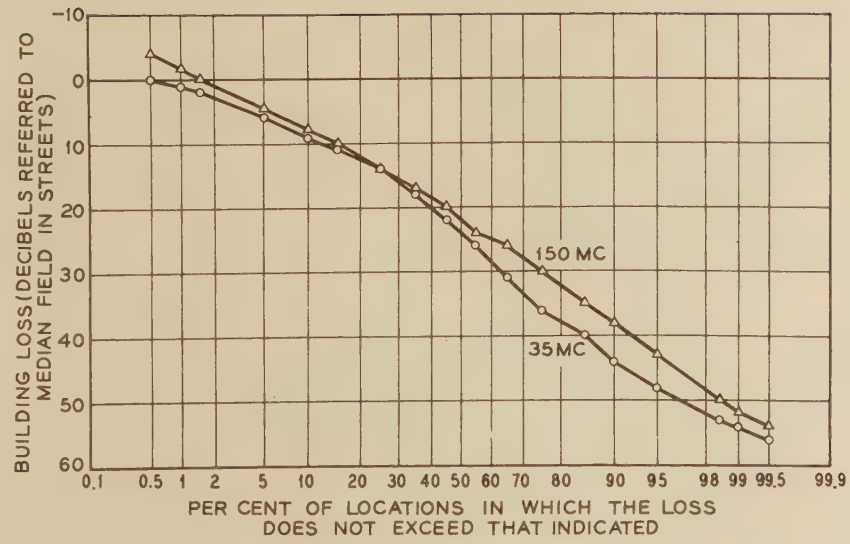
BUILDING LOSS (DECIBELS REFERRED TO MEDIAN FIELD IN STREETS)
-10
0
10
20
30
40
50
60
150 MC
35 MC
0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9
PER CENT OF LOCATIONS IN WHICH THE LOSS DOES NOT EXCEED THAT INDICATED

Fig. 11. Over-all distribution of building losses at 35 and 150-Mc.

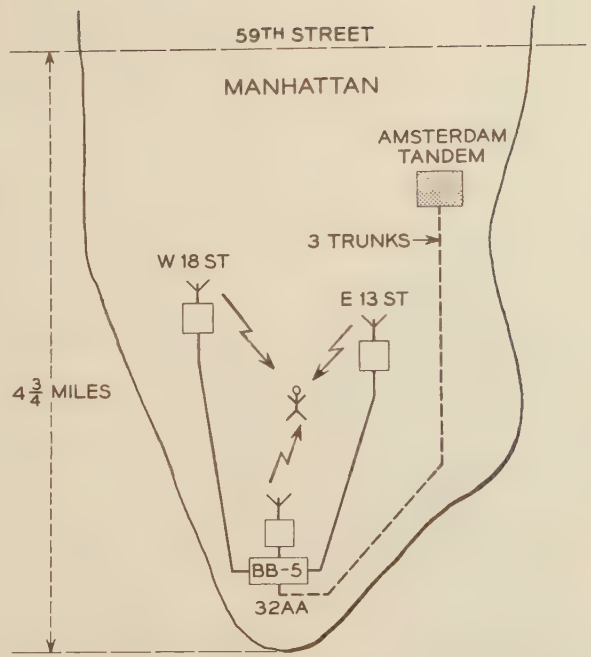

Fig. 13. Experimental trial of 150-Mc BELLBOY service in Manhattan.

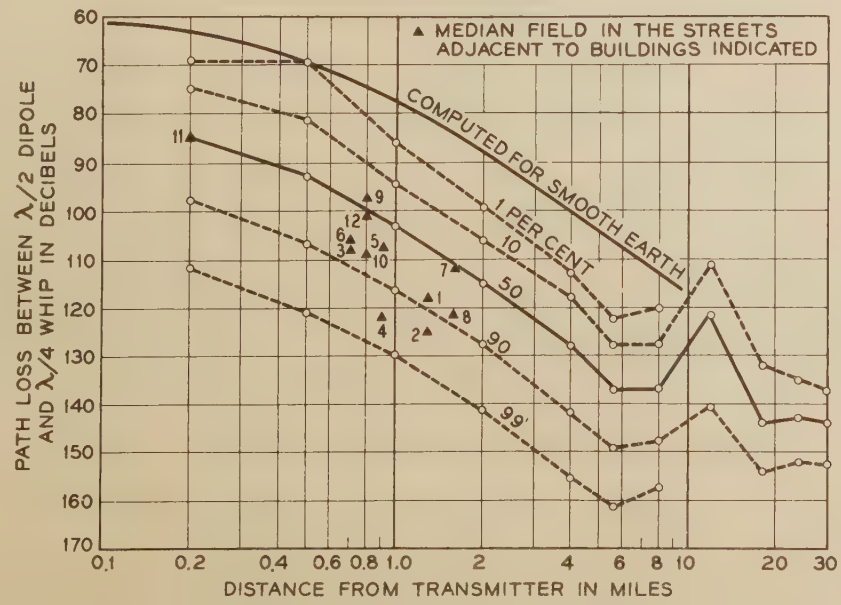

Fig. 12. Measured path loss at 150-Mc between a half wave dipole and a quarter wave whip in Manhattan and the Bronx and suburbs. Antenna heights, transmitter 450 feet; receiver 6 feet.

SPLITTING THE 450-MC CHANNELS

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Summary

A recently released FCC Notice of Proposed Rule Making, Docket No. 13847, contains a proposal to subdivide the existing 50 kc channels in the 450-470 mc private land mobile band into twice as many 25 kc channels.

Field and laboratory tests conducted to date indicate that the proposed technical standards can be successfully implemented in closely controlled test systems. Some significant problems may arise in actual "user" systems, however, if transmitters and receivers are not properly netted and held to a close RF channel tolerance. Considerable attention must be given to the various factors which determine the amount of receiver performance degradation experienced, if successful implementation of "same area" adjacent channel operation is to be achieved.

Existing 450 mc equipment of recent manufacture should provide adequate performance in most systems until the 25 kc split channels are assigned to new users in the same area.

Introduction

The continuing expansion of the private land mobile services has created severe channel congestion in many urban areas. In an attempt to relieve this congestion, the FCC has released a Notice of Proposed Rule Making which suggests changes in the technical standards of equipment presently licensed in the 450-470 mc private land mobile band.

This proposal, Docket No. 13847, would reduce authorized transmitter carrier deviation from the present 15 kc to 5 kc. Additionally, the Docket proposes that the present 50 kc channels be subdivided into 25 kc channels.

The Electronics Industries Association (Private Land Mobile Section) formed an engineering Ad Hoc committee to evaluate the possibility of maintaining present technical standards on 450 mc split channels and to generally investigate all problems relating to compatible systems design.

Suggested Technical Standards

The various equipment manufacturers participating in these tests found that retaining 15 kc carrier deviation in a 25 kc channel allocation plan, yielded only a 3 to 9 db reduction in the amount of interference which would be received if the two stations were operating co-channel. Further tests indicated that a reduction of transmitter deviation to $\pm$ 5 kc gave an average reduction of 20 db in adjacent channel interference. The 20 db, in this instance, is relative to the amount of interference which would be received if the stations were operating co-channel. The receivers used in these tests were current production units designed for $\pm$ 15 kc modulation acceptance.

Engineering tests conducted under carefully controlled conditions indicated that receiver selectivities comparable to those presently used in the VHF mobile bands, must be used if satisfactory "same area" split-channel systems performance is to be achieved.

Figure 1, shows a graphic illustration of the problems involved in operating on the proposed 25 kc channels. The curve can be used to determine the approximate magnitude of interference which can be expected from over deviation or inaccurate channel frequency adjustment.

The Frequency Stability Problem

Frequency stability is perhaps more correctly portrayed as two problems. Generally, an engineer views the problem from the standpoint of frequency drifts caused by ambient temperature, shock, and component part aging. There is another facet of the frequency stability problem, however, which must be recognized to a greater degree as technical standards become more stringent. Inadequate maintenance, inaccurate field frequency measuring equipment, and a careless service technician can contribute to channel frequency and system-netting errors in excess of the 0.0005% required by FCC rules.

Absolute transmitter and receiver frequency stabilities in excess of $\pm$ 0.0005% (5 ppm) are not readily obtainable at the present state of the art

without resorting to the techniques employed in high stability military equipments. These techniques are not generally compatible with the cost structure of present production mobile radio equipment.

Figure 2, shows the relative SINAD sensitivity degradation for present wide-band (designed for 15 kc modulation acceptance) and narrow-band (designed for 5 kc modulation acceptance) receivers. The degradation of the narrow-band receiver used with a transmitter having a frequency stability of 0.0001% (1 ppm) is approximately comparable to a wide-band receiver used with a transmitter having a frequency stability of 0.0005% (0.2 db in both cases).

In a practical field installation the receiver drift and frequency "netting" errors would have to be added to the transmitter frequency displacement. Under unfavorable conditions a frequency displacement of 5 kc between the transmitter and receiver is not rare. Using present production wide-band receivers, a SINAD sensitivity reduction of 1 1/2 db will be noted. A comparable frequency offset in a narrow-band receiver will cause a loss of 4 db in receiver sensitivity.

A highly refined AFC circuit can be used to improve substantially the performance of narrow-band equipment where reasonable signal strengths exist. The AFC circuit must have a high correction ratio to provide accurate frequency locking and have an effective boundary control to prevent locking on a strong adjacent channel station. All AFC circuits are subject to loss of control in weak signal areas. Therefore, a receiver which depends primarily on AFC to achieve system netting will not provide the fringe area coverage provided by high stability crystal controlled equipment.

Ignition Noise

Without minimizing the potential loss of system performance caused by a loss of the receiver SINAD sensitivity resulting from off-frequency operation, it should be pointed out that under the same conditions, a more severe loss of system performance will be contributed by motor ignition noise.

Figure 3, illustrates the need for proper frequency netting in a split-channel system. A 5 kc frequency offset can result in a 5 - 13 db degradation in the receiver 20 db quieting sensitivity for moderate ignition noise levels (60 db above 1 uv/mc). A high ignition noise level (80 db above 1 uv/mc) can cause a receiver degradation of 12 - 15 db. Ignition noise is more apparent in a split-channel system than it is in a comparable wide-band system, due to the pulse stretching properties of the highly selective IF filters used. The problem can cause significant performance degradation for even moderate system frequency displacements.

At the present state of the art, high stability crystals must be placed in a thermostatically controlled environment to maintain frequency over wide ambient temperature ranges. This factor presents another source of frequency error which can contribute to the system degradations noted in previous paragraphs. Generally, it will take several minutes for a crystal oven to reach its operating temperature. During the heating process the mobile unit may be several kilocycles off-frequency. In many types of systems this is of no concern. It may be a source of annoyance to some mobile users who expect their radio equipment to be functional as soon as it is turned on.

Channel Splitting Has Some Advantages

It can be demonstrated mathematically that an FM receiver will have a signal-to-noise ratio at the output of the discriminator which is proportional to the square of the ratio of frequency deviation to the IF bandwidth of the receiver. For the receiver selectivities shown in figure 2, (14 kc for wide-band receiver and 8 kc for narrow-band receiver) the split-channel system can be shown to have an FM improvement reduction of 9.4 db. Figure 4, illustrates a reasonable agreement with this value for the two receivers measured in the lab. It can be seen that this loss of signal-to-noise ratio only occurs with signals well above the receiver threshold. For most private land mobile systems the difference between a 40 db S/N ratio and a 50 db S/N ratio makes no significant contribution to intelligibility in speech communication.

When the peak signal voltage exceeds the peak noise voltage at the output of an FM receiver, an improvement in signal-to-noise ratio will be noted over a comparable AM system. As the noise bandwidth of the receiver and the modulation index of the transmitter are reduced, the FM improvement threshold occurs at lower carrier signal levels. Figure 4 illustrates a cross-over for narrow and wide-band receivers of approximately 0.8 microvolts. At 0.5 microvolt input the

narrow-band receiver exhibited an 8 db improvement in receiver signal-to-noise ratio.

It is the performance of the receiver at signal levels below 1 microvolt that determines the ultimate communication range of private land mobile systems located in low ambient noise areas.

Extensive field tests were conducted in the Chicago area to determine the relative performance of a wide-band mobile receiver with 5 kc and 15 kc deviation, and a narrow-band receiver using 5 kc deviation. All tests were actually conducted with the same receiver by changing the IF selectivity filter and the base transmitter instantaneous deviation control settings. Data from several hundred tests was fed into an IBM computer which calculated the median signal-to-noise curves shown in figure 5. The standard deviation for each of the three tests was also computed, but omitted from figure 5 for the sake of clarity.

The curves indicate the expected loss of signal-to-noise ratio for the wide-band receiver, as the base transmitter deviation is reduced. The curves indicate a loss in median signal-to-noise ratio of 6 db in strong signal areas, and a loss of only 2 db in fringe areas. The narrow-band receiver showed a significant improvement in signal quality in the weak signal areas, but dropped below the wide-band receiver for distances less than 10 miles from the base station.

Using the receiver characteristics shown in figure 4, and Bullington's propagation curves, we would expect the crossover to occur at a greater distance from the base station.

The data shown in figure 5 was taken on main thoroughfares in the Chicago urban and suburban area. The high ambient noise levels encountered tend to shift the relative positions of the various curves. Another factor which tends to affect the relative position of the curves is the mix of city and suburban test sites. Observation of the actual tests leads the writer to believe that the crossover point will generally occur between 10 and 15 miles for systems using the equipment noted in figure 5.

It must be stressed that the data presented is for standing vehicle operation and for equipment which was properly aligned and operating on-frequency. Further tests are being conducted to determine the effects of off-frequency operation on received signal quality.

Adjacent Channel Interference

Several potential sources of interference must be considered when designing vehicular communications systems to operate in the same area, on an adjacent channel basis.

* The receiver must be protected against strong adjacent channel signals which will desensitize it.
* Adequate separation must be provided to prevent transmitter noise sidebands and modulation splatter from masking weak signal reception.
* Receivers should be situated so that they are not in the field of high energy man-made noise.
* Care should be exercised in the choice of operating frequency to minimize intermodulation interference.

The first two points are rather difficult to separate in a practical system. Figure 6 illustrates the magnitude of receiver degradation caused by a VOSIM (voice simulator) modulated transmitter on an adjacent split-channel. For any desired signal strength, it is possible to predict the receiver degradation which will result if an adjacent channel signal is introduced into the receiver. As an example, consider a 2-microvolt signal which provides a 35 db SINAD signal in the absence of an interfering carrier. If an adjacent channel VOSIM modulated carrier signal is introduced into the receiver at a 20,000 microvolt level, the graph indicates that the SINAD ratio of the received signal will be reduced by 15 db or will now measure 20 db.

Using Bullington's signal propagation nomographs, it is possible to translate the measured data of figure 6 into the separation required between stations. A 7.6 mile separation between base stations is indicated if zero degradation of a 0.6 microvolt signal is required. Actually, the curve is very pessimistic since it does not consider the signal loss caused by terrain features and man-made structures. Typically, in a large city we would apply a 30 db systems use factor to Bullington's signal predictions. The dotted curve on figure 7 shows the zero db curve modified to account for the higher than normal city signal attenuation. Rural areas will require a

different set of curves somewhere between these two boundaries.

Ambient noise has a tendency to shift the family of curves to the left because of the receiver desensitizing effect.

Conclusion

The data in this paper is of necessity limited in scope. Many extensive field tests lie ahead before the problems involved in this type of system operation can be more adequately defined.

Several points stand out, however, which challenge both the equipment design engineer and the systems engineer.

1) Equipment frequency stability must be improved by another order of magnitude. The improvement must not significantly increase the cost of the equipment.

2) More investigations must be carried out to evaluate methods of sideband reduction in transmitters. This includes random noise sidebands.

3) More research is needed to improve the ability of receiver front ends to handle strong off-frequency signals without loss of on-frequency performance.

4) The systems engineer in co-operation with the FCC and equipment user groups must find some way to make allowances for equipment imperfections so that maximum use can be obtained from the new split-channels.

5) A co-ordinated program is needed to up-grade service technicians and field test equipment. This part of the problem is just as important as new equipment designs.

The projected 25 kc channelizing pattern proposed for the 450-470 mc mobile band represents the last subdivision which can be made for an extended period of time. This is particularly true when the economics of equipment fabrication are considered.

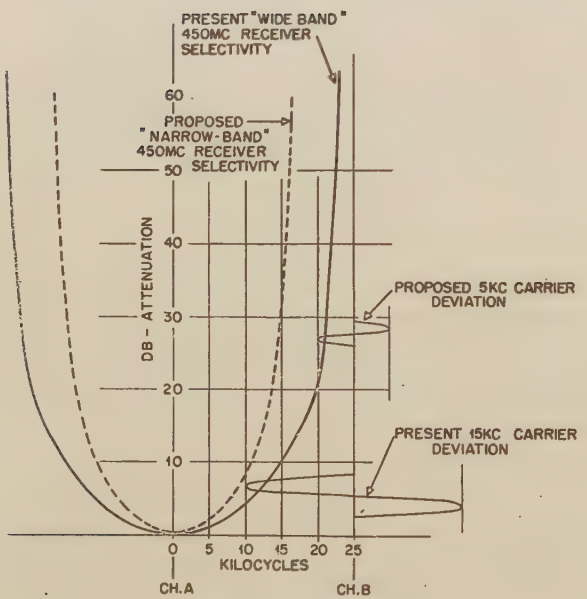

FIG. 1 RELATIVE INTERFERENCE POTENTIAL USING 5KC AND 15KC TRANSMITTER DEVIATION AND NARROW AND BROAD RECEIVER SELECTIVITY.

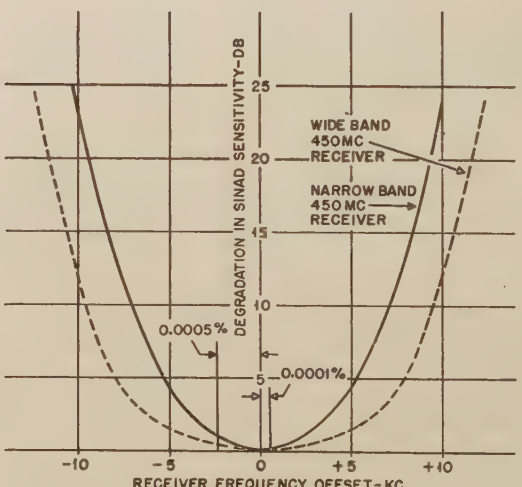

FIG. 2. RECEIVER SINAD SENSITIVITY DEGRADATION AS A FUNCTION OF CARRIER FREQUENCY OFFSET.

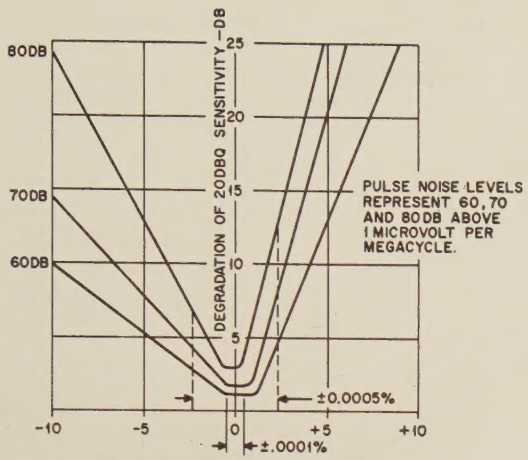

FIG. 3 NARROW BAND 450MC RECEIVER QUIETING SENSIVITY DEGRADATION AS A FUNCTION OF FREQUENCY OFFSET AND PULSE NOISE AMPLITUDE.

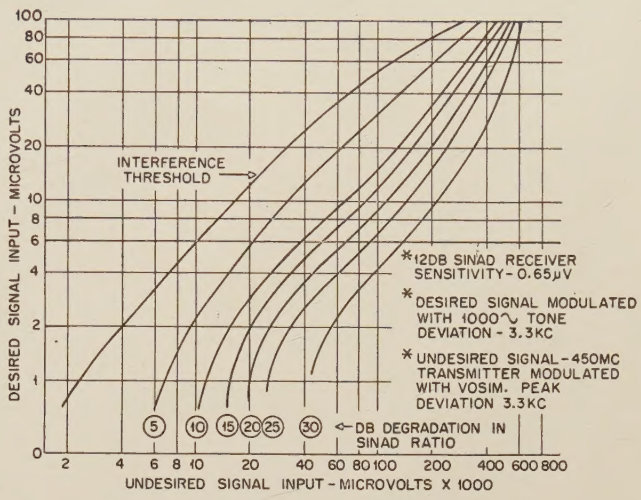
DESIRED SIGNAL INPUT - MICROVOLTS
INTERFERENCE THRESHOLD
*12DB SINAD RECEIVER SENSITIVITY - 0.65μV
*DESIRED SIGNAL MODULATED WITH 1000∿ TONE DEVIATION - 3.3KC
*UNDESIRED SIGNAL - 450MC TRANSMITTER MODULATED WITH VOSIM. PEAK DEVIATION 3.3KC
5 10 15 20 25 30 ← DB DEGRADATION IN SINAD RATIO
UNDESIRED SIGNAL INPUT - MICROVOLTS X 1000

FIG. 6 PERFORMANCE OF NARROW BAND 450MC RECEIVER SUBJECTED TO ADJACENT CHANNEL INTERFERENCE

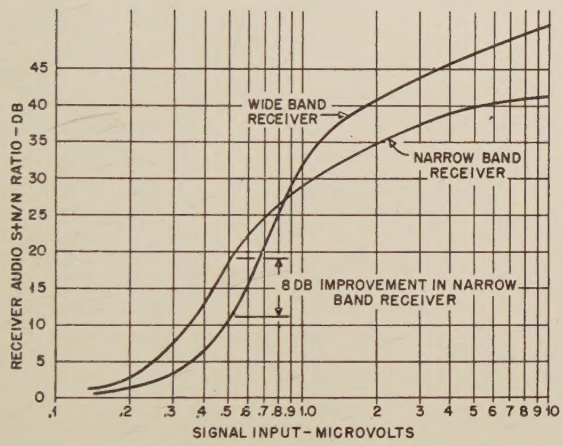
RECEIVER AUDIO S+N/N RATIO - DB
WIDE BAND RECEIVER
NARROW BAND RECEIVER
8 DB IMPROVEMENT IN NARROW BAND RECEIVER
SIGNAL INPUT - MICROVOLTS

FIG. 4. WEAK CARRIER S+N/N CHARACTERISTICS OF NARROW AND WIDE BAND FM RECEIVERS.

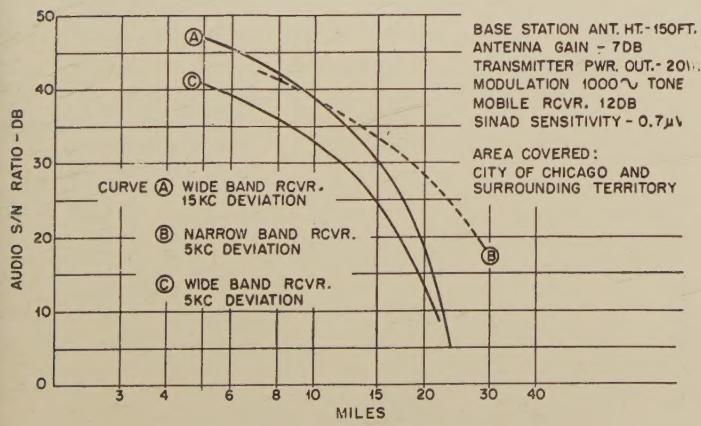
AUDIO S/N RATIO - DB
BASE STATION ANT. HT. - 150FT.
ANTENNA GAIN - 7DB
TRANSMITTER PWR. OUT. - 20W.
MODULATION 1000∿ TONE
MOBILE RCVR. 12DB SINAD SENSITIVITY - 0.7μV
AREA COVERED: CITY OF CHICAGO AND SURROUNDING TERRITORY
CURVE Ⓐ WIDE BAND RCVR. 15KC DEVIATION
Ⓑ NARROW BAND RCVR. 5KC DEVIATION
Ⓒ WIDE BAND RCVR. 5KC DEVIATION
MILES

FIG. 5 MEDIAN "STANDING VEHICLE" RECEIVED SIGNAL QUALITY

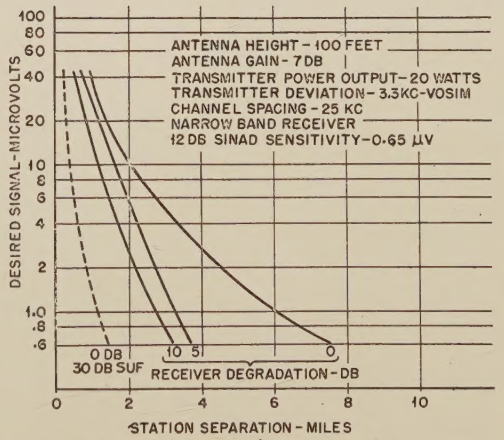
DESIRED SIGNAL - MICROVOLTS
ANTENNA HEIGHT - 100 FEET
ANTENNA GAIN - 7DB
TRANSMITTER POWER OUTPUT - 20 WATTS
TRANSMITTER DEVIATION - 3.3KC-VOSIM
CHANNEL SPACING - 25 KC
NARROW BAND RECEIVER
12 DB SINAD SENSITIVITY - 0.65 μV
0 DB
30 DB SUF
10 5 0
RECEIVER DEGRADATION - DB
STATION SEPARATION - MILES

FIG. 7. ADJACENT CHANNEL BASE STATION SEPARATION REQUIRED TO OBTAIN THE RECEIVER DEGRADATION INDICATED.

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